RADIO MANUAL

RADIO MANUAL

FOR THE INSTRUCTION OF MIDSHIPMEN

PREPARED FOR THE

U. S. NAVAL ACADEMY

DEPARTMENT OF ELECTRICAL
ENGINEERING AND PHYSICS

1928 EDITION

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PREFACE TO FIRST EDITION

The Department of Electrical Engineering and Physics at the Naval Academy has been unable to find a text book on Radio which is suitable for its purpose. This is due in the main to three reasons. First, most of the current books deal only with the popular side of radio, that is with the receiving end of the radio telephone. Second, most of the text books are either too comprehensive or not comprehensive enough to be included in thirty lessons, which is all the time that can be allotted to the subject at the Academy. Third, there has been such a rapid advance in the subject that it is difficult to find a text book that is up to date.

To meet the first two of these objections it was necessary for the E. E. and P. Department to have prepared a pamphlet which would meet the particular needs of the Naval Academy. In condensing this work an effort has been made to stress **principles.** Many details have necessarily been omitted. If the student can master principles, however, the details of the many different types of sets can be readily absorbed aboard ship with the aid of the special pamphlets which accompany each set.

To meet the third objection, this manual is published with each chapter a separate entity, a new series of pages, paragraphs, and figure numbers being started for each chapter. This arrangement will permit of any chapter of the manual being revised each year if necessary without disturbing the remainder of the pamphlet. Also additional chapters can be added as needed.

This manual was prepared by Comdr. G. S. Bryan, Comdr. R. F. Frellsen, and Lt. Comdr. S. Cochran, all on duty in the Department of Electrical Engineering and Physics. Most of the sketches were prepared by Lt. T. F. C. Walker, also on duty in the Department of Electrical Engineering and Physics. A few paragraphs and figures were taken from the "Principles Underlying Radio Communication," the book prepared by the Bureau of Standards for the Signal Corps, U. S. Army, and from the Bureau of Engineering, Navy Department's "Instructions for the Operation, Care, and Repair of Radio Plants."

G. F. NEAL,
Captain, U. S. Navy.

April 9, 1925.

PREFACE TO 1926 EDITION

The original Manual was revised and brought up to date by Lieutenant Commander S. Cochran, Lieutenant R. C. Moureau, Professor G. D. Robinson, and Professor E. W. Thomson, all of the Department of Electrical Engineering and Physics.

J. N. FERGUSON,
Commander, U. S. Navy.

September 2, 1926.

PREFACE TO 1927 EDITION

The 1926 Edition was revised and brought up to date by Commander F. W. Rockwell, Lieut. R. C. Moureau, and Professor G. D. Robinson, all of the Department of Electrical Engineering and Physics. Chapter VII was re-written by Dr. L. P. Wheeler of the Naval Research Laboratory. Through the courtesy of The Institute of Radio Engineers, the Report of its Committee on Standardization for 1926 has been added as a supplement.

J. N. FERGUSON,
Commander, U. S. Navy.

June 19, 1927.

PREFACE TO 1928 EDITION

The 1928 edition was completed in March in order that Midshipmen of the Second Class might begin the study of radio before making the Summer Practice Cruise. Besides many small corrections in the text, there have been added short articles on beam transmission, radio compass compensation, and the new screen grid vacuum tube. Due to the early revision there is no change in the Supplement as the 1927 Report of the Standardization Committee of the Institute of Radio Engineers had not been published. The work of revision was done by Commander F. W. Rockwell, Lieutenant C. W. Brewington, and Professor G. D. Robinson, all of the Department of Electrical Engineering and Physics.

J. N. FERGUSON,
Captain, U. S. Navy.

March 10, 1928.

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CHAPTER 1

1. **Introductory.** Any system of communication depends on the transmission of energy in some manner from one point to another. Various methods are used to accomplish this transmission. The telegraph and telephone systems are two methods of transmission. In wire telegraphy written messages transmitted by holding the telegraph key down for longer or shorter intervals in accordance with the Morse code cause variations in an electric current at the transmitting station and so cause corresponding responses in the apparatus at the receiving station. These responses are translated readily by the receiving operator by noting the intervals between the forward and back click of the sounder. In wire telephony words spoken at the transmitting station into a microphone whose resistance varies in unison with the varying air pressure caused by sound waves cause corresponding variations in the line current. At the receiving end the variations in current act upon a telephone receiver causing its armature to vibrate with the pulsating current and so generate sound waves similar to those spoken into the microphone.

2. In the wire telephone or telegraph the electric current is transmitted through wires between the two points. In many communication systems, however, use is made of some form of **wave motion,** the two types generally utilized being **sound waves** and **electromagnetic waves.** In radio telegraphy or telephony use is made of both of these types of waves. Although the subject of wave motion has been covered in the study of physics a brief summary will be given covering some of the points important in the study of radio communication.

WAVE MOTION

3. A periodic quantity is one that repeats the character of its variations after a time interval equal to its **period.** The succession of events or changes that occur within a period is called a **cycle** and is equal to two **alternations.** A "**Wave**" is a progressive disturbance in any medium formed by the propagation of alternating stress and strain through the medium and not by any actual transfer of the medium itself through space. The **Frequency** (f) of a wave is the number of cycles made per second, and is obtained by taking the reciprocal of the period, T, seconds per cycle, thus:—

$$f\,(\text{cycles per second}) = \frac{1}{T\ (\text{seconds per cycle})}$$

4. The **Wave Length** (λ) of a wave is the distance between two successive points of the medium whose vibrations are in the same **phase,** or the distance through which the wave travels in one period.

5. The **Amplitude** of a wave is the maximum displacement of the particles in the medium which transmits the wave.

6. Velocity depends on the type of wave and the characteristics of the transmitting medium. The frequency and wave length depend on the constants, mechanical or electrical, of the transmitting body. The amplitude depends on the amount of energy supplied to the transmitting medium. Changes in the amount of energy do not change the wavelength or the frequency.

7. It is a general fact, quite independent of the form of the wave, that the **velocity of a wave** equals the product of the **frequency** and the **wavelength,** or

$$V = f\lambda$$

8. The velocity of each type of wave is practically the same for all frequencies. Therefore, the frequency and wavelength are inversely proportional to each other.

TYPES OF WAVES

9. Each complete cycle produces a single complete wave. A number of waves produced consecutively in cyclical or nearly cyclical form constitute a **Wave Train.** According to their use in radio, it is customary to divide waves into the types described below.

These types are illustrated in Figure 1, the coordinates of the "wave" being instantaneous variations of an alternating current, voltage, the magnetic field in a circuit, the displacement or amplitude of the particles of the transmitting medium plotted as ordinates against time for abscissae.

10. **DAMPED WAVES.** If oscillations are set up, and no further energy is applied to maintain them, they may gradually die out, each succeeding amplitude being smaller than the preceding one. Such a train of waves is known as a **DAMPED WAVE TRAIN** and is illustrated in Fig. 1 (*a*).

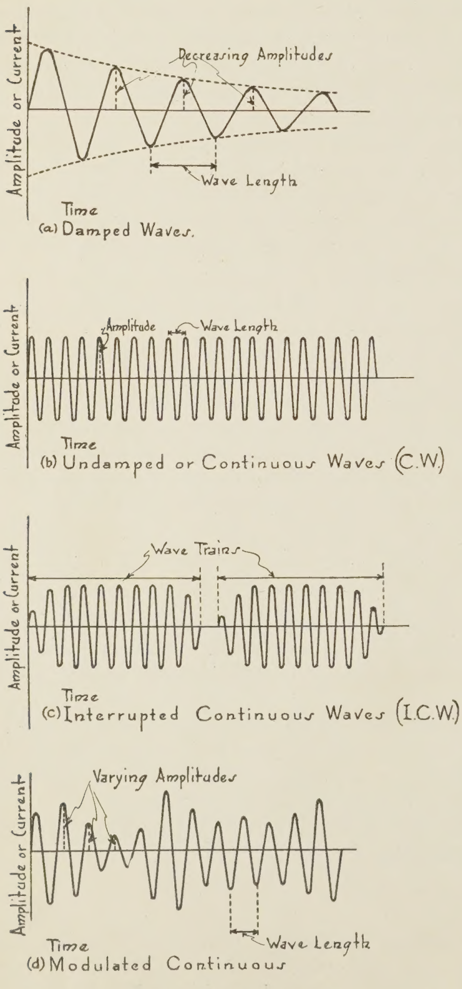


Fig. 1.—Types of Waves

11. **UNDAMPED WAVES,** or **CONTINUOUS WAVES** (generally abbreviated, "C.W."), are generated when oscillations are set up, and sufficient energy is supplied continuously to overcome all losses and maintain the amplitudes of the waves at a constant value. This is illustrated in Fig. 1 (*b*).

12. **INTERRUPTED CONTINUOUS WAVES.** (Generally abbreviated, "I. C. W.") This type of wave, as illustrated in Figure 1 (*c*), is the same as the continuous wave, with the exception that the wave is broken up or "interrupted" at audio frequency in a periodic manner. See supplement 1006. Due to practical considerations these groups of oscillations require a number of cycles to build up to a steady value and a number of cycles to die out. A special form of I.C.W. produced by vacuum tube generators when using AC plate supply is known as A.C.W.

13. **MODULATED CONTINUOUS WAVES.** If the energy supplied to maintain a continuous wave is varied, the amplitude of succeeding waves will follow these variations and we will have a **MODULATED CONTINUOUS WAVE,** as shown in Figure 1 (*d*).

SOUND WAVES

14. Sound waves are created by the setting in vibration of particles of air or other **matter.** The mechanical vibration of a diaphragm, such as that in a telephone, will accomplish this.

15. Sound waves are transmitted by the impact of the vibrating molecules on adjacent ones. They cannot be transmitted through a vacuum. They travel with a velocity in air of 1128 feet per second at 70° F.

16. When sound waves strike the drum of

the ear, they set it in vibration and produce the sensation which we call **sound**. In order to produce this sensation, the **frequency** of the waves must lie **between certain limits**; otherwise no sound will be heard. Roughly, these audible limits of the frequency lie between 20 and 20,000. The human ear is most sensitive to sound waves of a frequency in the neighborhood of 1,000.

17. Changes of electric current in the coil of a telephone receiver set the diaphragm in vibration causing it to set up sound waves which are detected by the ear. Alternating current of frequencies coming within the audible limits given above, if passed through a telephone receiver, will cause the diaphragm to set up waves which are audible. These frequencies are called **audio frequencies.** If the alternating current is of a frequency outside the audible limits, no sound can be heard, even though sound waves are set up. Therefore, whatever the nature of the signal received, it must be converted to an **audio frequency** before it can be **heard.**

18. The **FREQUENCY** of a series of waves determines the **pitch** of the sound.

19. The **AMPLITUDE** of the wave, which depends on the energy of the vibrations, determines the **intensity** or **loudness** of the sound.

ELECTROMAGNETIC WAVES

20. In radio communication, the transfer of energy is made by means of **electro-magnetic waves.** These waves are transmitted by a vibration or strain in the ether and not by matter, so that they pass readily through a vacuum. Their velocity is that of light; i. e., 3×10^8 meters per second, or 186,000 miles per second (in air or vacuum).

21. Electromagnetic Waves are created by a disturbance of an electromagnetic nature which sets the adjacent ether particles in vibration, and produces around the point of disturbance a varying magnetic field and a varying electric field. These fields are at right angles to each other, and both are at right angles to the direction of propogation of the wave.

22. While the general nature of all electromagnetic waves is the same, they comprise a number of types such as light waves, heat waves, X-Rays, etc., which produce greatly different effects. These can be grouped generally according to their frequencies or wave lengths. The following table-which need not be memorized-gives a summary of the most important waves:

Name	Mean Frequency in Cycles	Mean Wave Length in meters (in air)
X Rays	4.7×10^{15}	6.38×10^{-8}
Ultra-Violet Rays	3×10^{15}	1×10^{-7}
Light Waves Violet	8.33×10^{14}	3.6×10^{-7}
Light Waves Red	to 3.7×10^{14}	8×10^{-7}
Infra Red or Heat Waves	3×10^{13}	1×10^{-5}
Radio Waves	3×10^{8} to 10^4	1 to 3×10^4 in common use.

For all these electromagnetic waves, the velocity $= f$ cycles $\times\ \lambda$ meters $= 3\times10^8$ meters per second, for instance, $V = f\lambda = 3\times10^{15}\times10^{-7} = 3\times10^8$ meters per second.

23. The above table shows that the frequencies of electromagnetic waves **used in radio** are generally much higher than the frequencies of sound waves given in paragraph 16 and for that reason they are known as **radio frequencies** (abbreviated "r.f.") as distinguished from the audio frequencies mentioned in paragraph 16 and 17. One of the problems of radio communication is to produce apparatus which will receive radio frequencies and turn out a related audio frequency, or vice versa.

TYPICAL RADIO SETS

24. **Typical Radio Transmitter.** The general action of a radio sending set both telegraph and telephone is as follows:

(a) An alternating electrical current oscillating at a radio frequency is set up in an **electrical circuit** (radio frequency currents are used because power radiated from an antenna increases **very rapidly** with increase in frequency).

(b) These oscillations are either interrupted or varied according to the signal to be transmitted.

(c) The oscillations of current, modified as in (b) are made to set up similar oscillations in the ether, which radiate off into space from the antenna as electromagnetic waves.

25. **Typical Radio Receiver.** In the **receiving** set, the reverse of the above takes place.

(a) The electromagnetic waves described in the previous paragraph move past the receiving antenna and induce in that circuit corresponding oscillations of voltage which are transferred to the detector;

(b) The detector of a rectifying type converts the modulated radio frequency power into audio frequency power;

(c) The receiving apparatus thus produces audio frequency currents to which the diaphragm of a telephone receiver will respond. These audio frequency oscillations correspond to the **variations** in the radio frequency currents.

CHAPTER II

RESISTANCE, INDUCTANCE, CAPACITY AND RESONANCE

1. It should constantly be borne in mind that radio circuits are all designed to apply principles of direct and alternating currents. Frequently, through a portion of the circuit, only one path is provided to carry both the AC and DC components simultaneously. Therefore the experimental facts about resistance, inductance, and capacity should be reviewed before any further study of high frequency phenomena is undertaken.

RESISTANCE

2. **DIRECT CURRENT RESISTANCE.** In a direct current circuit the resistance is a function of the kind of wire used in the circuit, its length, and cross-sectional area,

$$R = \frac{\rho l}{A} \text{ ohms} = \frac{kl}{d^2} \text{ ohms.}$$

Also the current in the circuit is always proportional to the voltage impressed on the circuit; $I = \frac{E}{R}$ amperes. The power dissipated in the circuit or turned into heat is equal to $P = I^2R$ watts, where I is the constant value of the direct current in amperes, R is the resistance in ohms, and P is the power in watts. The energy used up is $W = I^2Rt$ joules or watt-seconds, where t is the time in seconds that the current is flowing.

3. **RESISTANCE IN RADIO CIRCUIT.** In alternating current circuits there are several other factors which enter into the resistance beside length and area. In a radio circuit the resistance is due not only to the resistance of the conductor itself, but to the resistance of neighboring circuits, the presence of magnetic material near the circuit, the dielectric losses in condensers or elsewhere, and the radiation of electromagnetic energy from the circuit. All of these factors vary with the frequency.

4. **SKIN EFFECT.** For high frequencies it is found that the resistance of a conductor increases due to the fact that a large part of the current travels in the outer layers of the wire. This phenomenon is called the **skin effect.** For high frequencies the resistance of a wire varies directly, but not in simple proportion, with the product of its radius and the square root of the frequency. For a 300 meter wave, i. e., $f = 10^6$ cycles per second, and a copper wire of radius 1 cm. the A.C. resistance due to the skin effect is 70 times the D.C. resistance.

5. **HYSTERESIS AND EDDY CURRENTS.** For electric circuits coiled around or adjacent to magnetic material there is a loss of energy due to the repeated reversals of flux through the magnetic circuits. This is called **hysteresis loss** and is included as part of the resistance losses. In any mass of metal near the A.C. circuit induced currents are set up which also cause losses included as part of the resistance losses. These currents are called **eddy currents** and the losses may be decreased by laminating the metal, thus increasing the resistance path of the eddy currents.

6. **EFFECTIVE RESISTANCE.** It is seen therefore that resistance in an A.C. circuit is no longer a simple factor. All of these heat losses in a circuit, whether due to conductor resistance, eddy currents or hysteresis are said to be resistance losses, where the **effective resistance of an A.C. circuit is defined as the ratio of the power loss to the square of the current.**

$$R = \frac{\text{power loss}}{I^2}; \text{ or } P = I^2R \text{ watts.}$$

7. **PHASE RELATION WITH RESISTANCE ONLY.** If the current through a circuit containing resistance only is varying as a Simple Harmonic disturbance according to a sine law, then the instantaneous value of current $i = I_m \sin \omega t$. Then as the voltage or potential drop across the resistance to maintain this current is $e = iR$, then $e = iR = I_mR \sin \omega t$. It is seen that as both i and e vary with the sine of the phase angle that **i and e are in phase.** When $i = 0$, $e = 0$ and when $i = I_m$, $e = I_mR = E_m$.

8. **EFFECTIVE CURRENT.** In the above and subsequent discussions i and e are used for the instantaneous values of current and voltage, I_m and E_m for the maximum values, and I and E for the effective values.

The square root of the mean of the squares of the instantaneous values of an alternating current over a complete period is called the effective or root mean square value of the alternating current. In specifying the value of an alternating current as so many amperes this effective value is always meant unless specifically stated otherwise. The average power dissipated as heat in a resistance R, where an alternating current of effective value I flows through it, is I^2R. Also the deflection of all instruments used in alternating current measurements is a function of this effective value. (See Bullard, Vol. 1, 1922, paragraph 46, page 490, et seq.)

$$I = \sqrt{\frac{1}{T}\int^{t} i^2\,dt}, \text{ where } T = \text{Period} = \frac{1}{f} = \frac{2\pi}{\omega}.$$

If the graph of the instantaneous current is plotted the effective value may be found by evaluating the average instantaneous i^2 by any means of mathematical summation.

$$I = \sqrt{\frac{i_1^2 + i_2^2 + i_3^2 + \cdots + i_n^2}{n}}$$

If the current varies with the sine or cosine of the phase angle then $I = \frac{I_m}{\sqrt{2}} = .707\ I_m$.

INDUCTANCE

9. **MAGNETIC FLUX AND INDUCED E.M.F.** Whenever current passes through a wire it sets up a magnetic field about the wire and the strength of the magnetic field varies as the current varies. The magnetic flux thereby set up represents a certain amount of energy and this energy must be taken from the energy of the circuit.

Whenever the magnetic field threading an electric circuit changes, an electromotive force is induced in the circuit. When each turn of the circuit links the same number of flux lines, the total induced electromotive force in a coil of N turns is

$$e = -N\frac{d\phi}{dt} \text{ abvolts} = -\frac{N\frac{d\phi}{dt}}{10^8} \text{ volts.}$$

The negative sign states the experimental fact that the change in the magnetic flux sets up an electromotive force which tends to produce a current around the circuit in such a direction as to set up an **opposing flux.**

10. **COUNTER ELECTROMOTIVE FORCE.** When the current in a given electric circuit varies with time, the magnetic flux accompanying this current also varies with time, and since this flux links the circuit which produces it, an electromotive force is induced. This electromotive force is in such a direction as to oppose the change in current. Thus an increasing current is always accompanied by a back electromotive force due to the increase in the magnetic flux and this tends to decrease the current. When an electric current decreases, its accompanying flux decreases and an electromotive force is set-up tending to oppose the decrease, that is, tending to keep the current flowing.

11. **SELF-INDUCTANCE.** The above **electromagnetic inertia** effect of a circuit is said to be due to the **self-inductance of the circuit**. The self-inductance of a circuit, L, is defined from the equation for induced e.m.f. in a circuit,

$$e = -L\frac{di}{dt} = -N\frac{d\phi}{dt},$$

from which $L = N\dfrac{d\phi}{di}\cdot$

The self-inductance of an electric circuit is therefore the coefficient that the time rate of change of current must be multiplied by in order to give the back electromotive force induced. Or, the self-inductance of a circuit is defined as the product of the number of turns in the circuit and the rate of change of flux with respect to current. If in the above formulae e is in volts, i is in amperes, and t is in seconds, then L, the self-inductance of the circuit is in henries. That is, when a rate of change of current of one ampere per second induces a counter electromotive force of one volt in a circuit, the circuit is said to have an inductance of one henry. The henry is a rather large unit for work with radio frequency circuits so the smaller derived units, millihenry (mh), and microhenry (μh) are used.

12. **FACTORS INFLUENCING INDUCTANCE.** As flux is an accompaniment of any circuit, and as inductance is proportional to the change in flux, then **all circuits have a certain amount of inductance.** A straight wire has an inductance which is proportional to its length, and is also a function of its radius and permeability. Bars or strips of material also have inductance. All loops and coils of wire have inductance proportional to the length of wire contained. For a long air solenoid of length l, of circular cross-section A sq. cm. having N turns, the self-inductance is,

$$L = K\,\frac{4\pi\, N^2A}{10^9 l}\ \text{henries}$$

that is, L is a function of the number of turns, the cross-sectional area, the turns per centimeter, the total length of wire, and the shape (K is a form factor less than unity depending on the ratio A/l, etc.). If the solenoid contains iron, the inductance is also proportional to the permeability μ of the iron. A straight wire has "distributed" inductance, whereas a coil is said to have "concentrated" inductance.

13. **EFFECT OF INDUCTANCE IN DIRECT CURRENT CIRCUIT.** In a direct current circuit the effect of inductance is to cause a slowing-up or lagging of changes in current, so that when a switch is closed the current does not immediately rise to its maximum value $I = \dfrac{E}{R}\cdot$ If the switch K, of Figure 1a is closed the battery of electromotive force E_x tends to drive a current through the inductance L and resistance R. Due to the back electromotive force developed in the inductance, $e = -L\dfrac{di}{dt}$, the current is momentarily decreased and the current at any instant is;

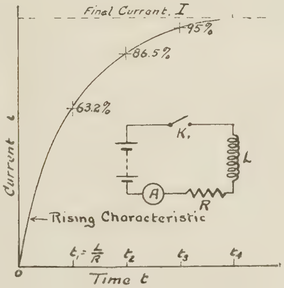


FIG. 1a.—Rising Characteristic.

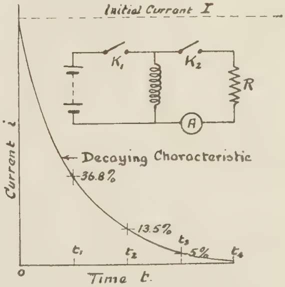


FIG. 1b.—Decaying Characteristic.

Fig. 1. Effect of Inductance in Direct Current Circuit.

$$i = \frac{E_x - e}{R} = \frac{E_x - L\dfrac{di}{dt}}{R}.$$

If we plot the value of this instantaneous current we get the **rising characteristic** of Figure 1a. The equation for this which may be developed from the previous formula becomes:

$$i = \frac{E_x}{R}(1 - \epsilon^{-\frac{Rt}{L}})$$

Where ϵ=natural base of logarithms=2.7183, R=resistance in ohms of whole circuit.

The inductance L has then been charged so that if the switch K_2 is closed and K_1 opened (Figure 1b) the inductance will discharge through the resistance due to the inertia effect of the inductance, and the energy of the magnetic field of the inductance will be dissipated as heat in the resistance.

The instantaneous current

$$i = +\frac{L\,di}{R\,dt} = \frac{E_x}{R}\left[\epsilon^{-\frac{Rt}{L}}\right]$$

and this plots as in Figure 1b, the **decaying characteristic.**

14. **TIME CONSTANT.** A study of Figure 1 shows that in a D.C. circuit this lagging effect of inductance is appreciable only momentarily. For instance if we set $t = \frac{L}{R}$ then $i = 63.2\% \ I$, that is, the current will rise to 63.2% of its final value in a time equal to the ratio of L/R, if the switch is closed; and will fall to 36.8% of its maximum value in this time when the switch is opened. This time L/R is called the time constant of the circuit. The final value of the current, though, will be that predicted by Ohm's Law $I=E/R$.

15. **INDUCTANCE IN A.C. CIRCUITS.** In an alternating current circuit the inductance causes two effects, one the decreasing of the current and the other, the lagging of the current in phase 90° behind the voltage. The momentary lagging of the value of current behind that finally reached as in D.C. is also present. If the current in the circuit is varying as the **sine function** of the phase angle, then $i=I_m \sin \omega t$; and as the electromotive force to overcome the induced electromotive force $= L\frac{di}{dt}$, then $e = L\frac{di}{dt} = \omega\ L\ I_m \cos \omega t = E_m \cos \omega t$. That is, if the current varies with the sine of the phase angle the electromotive force to maintain this current through the inductance varies with the cosine of the phase angle. When

$\omega t=0,$	$i=0,$	$e=+E_m,$
$\omega t=\pi/2,$	$i=+I_m,$	$e=0,$
$\omega t=\pi,$	$i=0,$	$e=-E_m,$
$\omega t=3\pi/2,$	$i=-I_m,$	$e=0$

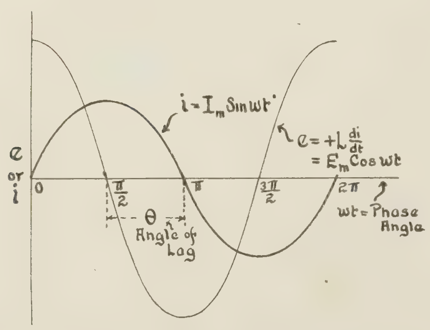


FIG. 2.—E and I in Inductance.

The relation may be expressed better by saying that in a **circuit containing inductance only, the current lags the voltage by 90° or $\pi/2$.** That is, the current passes through a value (0, +max. or −max.) later than the voltage by an amount 90° or $\pi/2$ radians or $T/4$ seconds, the value of e being a function of the rate of change of i.

16. **CURRENT IN INDUCTANCE.** The value of the current in an inductive circuit may be found from the statement that $\omega LI_m=E_m$. As the ratio of E_m/I_m is the same as E/I, and as $\omega=2\pi f$ then $X_L=E/I=\omega L=2\pi fL$ ohms, where X_L is called the inductive reactance of the circuit, f is the frequency in cycles per second, and L is the inductance in henries. $I=\frac{E}{X_L}=\frac{E}{2\pi fL}$ amperes

in a circuit containing inductance only. The current therefore in an inductive circuit is inversely proportional to the frequency and to the inductance.

17. **FREQUENCIES.** In A.C. work different terms are used for the different bands of frequencies used. **Commercial power circuits** have low frequencies, 25 and 60 cycles per second being representative. **Audio frequency circuits** are those which vibrate at frequencies that can be heard, roughly 20 to 20,000 cycles per second, 200 to 3,000 cycles per second being sufficient for speech transmission, 1,000 cycles per second being the most audible to the average ear. **Radio frequency circuits** have frequencies from about 10,000 to 20,000,000 (or more) cycles per second, 600,000 (600 kcs.) being representative.

18. **CHOKE COILS.** The formula $X_L = 2\pi f L$ shows at once that the inductive reactance is directly proportional to the frequency. Therefore, a given inductance L, which offers but comparatively small reactance to frequencies from 25 to 60 cycles, to which we are accustomed in commercial work, offers an enormous reactance to currents of radio frequencies. Therein lies the explanation of the action of a coil to "choke back" radio frequency currents while permitting low or audio frequency currents to pass more readily. An inductance used for this purpose is called a "choke coil." A coil of given inductance which has a certain reactance at 600 kilocycles would have only one ten-thousandth of that reactance at 60 cycles. If the coil is subject to two alternating electromotive forces of the same value, one having a frequency of 600 kcs. but the other having a frequency of only 60 cycles, the current in the first case will be, say, 0.0001 amp., whereas in the second case it will be 1 amp. This shows that the coil reduces enormously the radio frequency current, but readily passes the low frequency current. On the other hand, a coil which is designed to choke back a 60-cycle alternating current may pass easily a direct current. Such a coil might also pass readily a radio frequency current because of the capacity between the turns of the coil, the coil having the effect of an inductance and a capacity in parallel.

19. **ENERGY IN INDUCTIVE CIRCUIT.** In order to set up a magnetic field a certain amount of energy must be expended. It may be proved that the energy represented by the magnetic field is $W = \frac{1}{2} L I_m^2$ joules or watt-seconds. When the current is increasing, the field strength is increasing and energy must be taken from the power line. If the current is decreasing, the field strength is decreasing (collapsing) and this energy is returned to the line. If this interchange of energy between field and circuit goes through a whole number of cycles the total energy and power used equals zero. However in all practical inductance coils there is a finite resistance and the power used by this resistance, $P = I^2 R$ watts, or the energy, $W = I^2 R t$ joules, cannot be returned to the circuit and is dissipated as heat, radiation, etc.

20. **MUTUAL INDUCTANCE. INTERLINKAGE.** When a coil is not under the influence of another circuit we speak of its **self-inductance,** this being the measure of the property of the coil to oppose any change in current in the circuit. When however any portion of the flux from one coil is linked with the turns of another coil these coils are said to possess **mutual inductance.** Transformer action is based on mutual inductance. If in Figure 3, the switch K is closed a current will be sent through the L_1 circuit and a magnetic field will be built up about L_1. As this field cuts the coil L_2 an induced electromotive force proportional to the rate of cutting ($d\phi/dt$) will be set up in the coil L_2. The two coils are said to have a mutual inductance M existing between them, where this is defined from the equation $e_2 = -M \frac{di_1}{dt}$. When a rate of change of one ampere per second in the primary winding induces an electromotive force of one volt in the secondary the two coils have a mutual inductance of one henry.

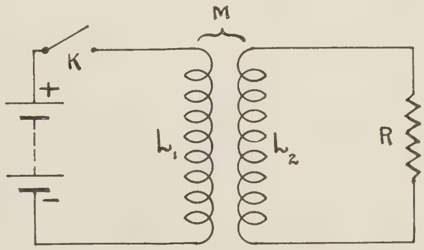


FIG. 3.—Mutual Inductance.

21. **COUPLING THROUGH MUTUAL INDUCTANCE.** Two coils possessing interlinkage of flux lines are said to be inductively coupled. The coefficient of coupling is a measure of the percentage of the flux from the primary which links the secondary. The coupling is therefore a measure of the portion of the energy in one circuit which may be transferred in one cycle to another by these flux interlinkages. For the coils of Figure 3, the coefficient of coupling $K = \dfrac{M}{\sqrt{L_1 L_2}}$.
The coupling between two coils may be increased by moving the coils closer together, by placing the coils around an iron circuit as in a power transformer, or by making the coils parallel to each other. By each of these methods the mutual inductance is increased. The main use of mutual inductance coupling is that energy may be transferred between two insulated circuits due to the flux interlinkages. "Coupler," "tickler" and "oscillation transformer" are names applied to various types of mutual inductance couplings in radio work where energy is transferred from a coil in one circuit to a coil in another.

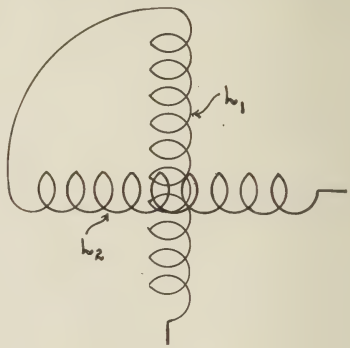


Fig. 4.—Variometer.

22. **VARIOMETER.** The **"Variometer"** is a device utilizing variable inductive coupling to change the self-inductance of a circuit. In this device two coils, the wires of which are usually connected in series, are rotated with respect to one another. A mutual inductance exists between the two coils (even though they are in series), and this may be made to buck or assist the self-inductance so that the effective inductance of the circuit changes from L_1+L_2-2M to L_1+L_2+2M (if the coils are in series). In Figure 4 with the two coils at right angles the mutual inductance is a minimum and the inductance of the circuit is merely L_1+L_2.

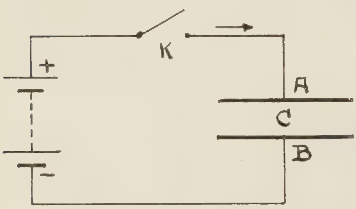


Fig. 5.—Capacity Circuit.

23. **AIR vs. IRON CORES.** The above examples of coupling all have air cores. The inductance and coupling may be increased by the use of iron cores and this is done in audio frequency transformers where the increased reactance is not exorbitant as it would be with iron cores in radio frequency circuits. Most metal cores in radio work are made of thin laminations of silicon steel to decrease eddy currents.

CAPACITY

24. **CAPACITY AND CONDENSERS.** Whenever two metallic conductors are separated by an insulator (dielectric) these two conductors may be maintained at a difference of potential by applying a suitable electromotive force. For instance suppose A and B, Figure 5, are two conducting plates, with mica, air or glass between them in the space C Such a device for storing electricity is called a condenser. If the switch K is closed it will be found that a momentary current will flow in the direction as shown, but that this current will soon stop, even though the battery still has an e.m.f. of 6 volts. This stoppage of current shows that the condenser has developed an electromotive force equal, but opposite, to the applied e.m.f. If we apply a suitable voltmeter to A and B we find, (even after the switch K is opened), that A has a greater potential than B by 6 volts. In order that the difference in potential may exist between A and B the electrons in the intervening space must have been redistributed. We actually think that the plate A has a positive charge ($+$Q) and the plate B has a negative charge ($-$Q), these charges having been set up by the current flowing for a certain

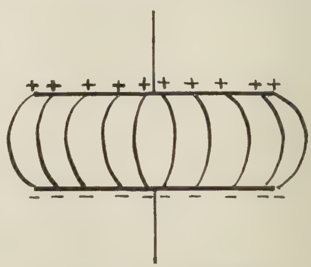


Fig. 6.—Charged Condenser.

time. By definition $i = \frac{dQ}{dt}$, or $Q = \int_0^t i\,dt$. Each + charge on A is "bound" to an equal − charge on B and we have established an electrostatic field between A and B, made up of charges bound by electrostatic lines. The electrons in the space C have been redistributed, the strain between the electrons being represented by the electrostatic field.

25. **CAPACITY.** This process of applying an electromotive force to a condenser, redistributing the electrons, and setting up an electrostatic field is called **charging the condenser.** It is found that the number of unit charges or the amount of charge, (coulombs = summation of amperes × sec.), is proportional to the voltage applied to the condenser, and that the charge varies with the particular condenser. $Q = CE$ where Q = charge in coulombs and E = electromotive force in volts. The factor C is called the **capacity of the condenser.** A condenser has a capacity of **one farad** if a charge of electricity of **one coulomb** raises its potential **one volt.** The farad being too large for radio work the smaller derived units in use are the microfarad (μf) and the micromicrofarad ($\mu\mu$f). The millifarad is not used as a unit.

The capacity of a condenser is dependent upon the material of the dielectric, K, the area of the plates, A sq. cms., and the distance between the plates or thickness of dielectric, d cm.

$$C = \frac{KA}{4\pi d} \text{ electrostatic units} = \frac{KA}{4\pi \times 9 \times 10^{11} d} \text{ farads} = \frac{KA}{4\pi \times 9 \times 10^{5} d} \mu f$$

K is known as the dielectric constant, or the specific inductive capacity of the dielectric and has values of 1 for air, about 6 for mica, 5 for bakelite, 2.5 to 10 for glass.

26. **ENERGY IN CONDENSER.** The electrostatic field of the charged condenser contains a certain amount of energy as it has required a current flowing for a certain time to set up that field $W = \int_0^t ei\,dt = \frac{1}{2}QE_m = \frac{1}{2}CE_m^2$. That is, the energy in the condenser is proportional to its capacity and the square of the maximum impressed voltage.

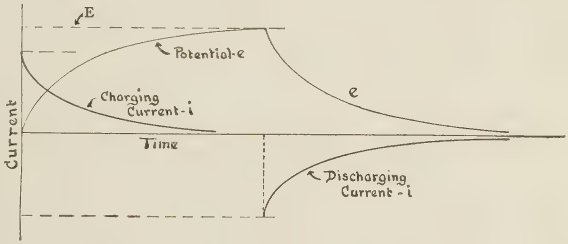


FIG. 7.—Charge and Discharge of a Condenser.

27. **CAPACITY IN D.C. CIRCUIT.** In a D.C. circuit a condenser is charged by a momentary flow of current. As the condenser becomes charged, the current decreases or stops, the capacity acting as a break in the line. The value of the current at any instant $i = \frac{E}{R}(\epsilon^{-\frac{t}{RC}})$, where RC is the time constant of the circuit and equals the time for the current to fall to 36.8% of its maximum value. (Compare with paragraph 14).

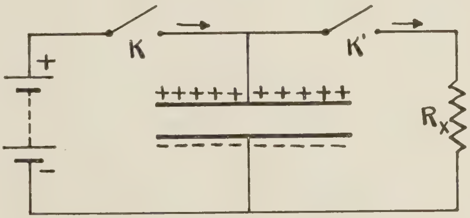


FIG. 8—Condenser and Resistance.

If now the charged condenser of figures 5 and 6 is disconnected from the battery and connected by means of the switch K' (Figure 8) to a circuit of resistance R_x it is found that the condenser drives a momentary current through R_x in the direction shown, the condenser acting as a battery, the upper plate plus and the lower minus. The value of this current $i = -\frac{E}{R_x}(\epsilon^{-\frac{t}{RC}})$ the same as charging except in the opposite direction through the condenser as shown by the negative sign (See Figure 7.).

The current will die down as the electrostatic field collapses and the electromotive force of the condenser is reduced to zero. This process is called **discharging a condenser.** The energy of the field $\frac{1}{2}CE_m^2$ has been used up in heating the resistance R; $W=\int Ri^2\,dt=\frac{1}{2}C\,E_m^2$.

28. **CAPACITY IN A.C. CIRCUIT**. In an alternating current circuit containing capacity the capacity has several effects. Due to the alternating shift in the impressed electromotive force an alternating current is maintained through the condenser. If the electromotive force has an instantaneous value $e = E_m \sin \omega t$ then the instantaneous current $i = \frac{dQ}{dt} = C\frac{de}{dt} = \omega C\,E_m \cos \omega t$.

When the phase angle $\omega t=0$, $e=0$ and $i=I_m$; when $\omega t=\pi/2$, $e=E_m$ and $i=0$; when $\omega t=\pi$, $e=0$ and $i=-I_m$; when $\omega t=3\pi/2$, $e=E_m$ and $i=0$. That is, the current i reaches a particular maximum $\pi/2$ or 90° before the voltage which maintains the current. **Hence in a capacitive circuit the current is said to lead the voltage 90°.**

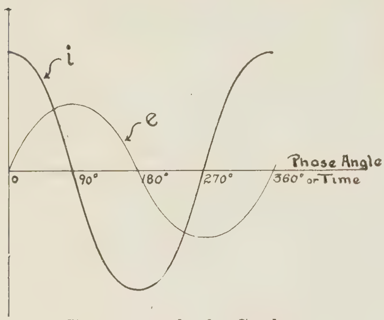


FIG. 9.—i and e for Condenser.

Also, as the maximum current $I_m=\omega CE_m$, then $\omega C=\frac{1}{X_c}$ where X_c is the reactance tending to decrease the value of the current. Hence $X_c=\frac{1}{\omega C}=\frac{1}{2\pi fC}$ where f=frequency in cycles/sec., C=capacity in farads, X_c= reactance in ohms. This formula shows that the capacitive reactance is inversely proportional to the frequency. Therefore, with a given capacity and a constant electromotive force, the current will increase with increase of frequency since $I=E/X_c$ amps., X_c decreasing as f increases.

29. **POWER IN CAPACITY CIRCUITS**. The power used up in a condenser is equal to zero, assuming the condenser has no resistance, as the energy $\frac{1}{2}CE_m^2$ taken from the line in charging the condenser is returned to the line in discharging. However, there are some electrostatic hysteresis losses in the dielectric which use up some energy and these are equivalent to a small effective resistance in series with the capacity. For direct current there is sometimes a small current leakage through a condenser and this is equivalent to a high D.C. resistance in parallel with the capacity.

30. **SUMMATION OF CAPACITY EFFECTS.** Only after several cycles have passed in a capacitive circuit does the current actually lead the voltage by 90° or assume a definite value $I = \frac{E}{X_c}$.

The three effects of capacity in an A.C. circuit are then: (1) to allow a current to flow of effective value $I=2\pi fCE$, (2) this current will lead the voltage by 90° finally, but (3) this effect will not take place for several cycles.

31. **CAPACITY EFFECTS IN RADIO FREQUENCY CIRCUITS.** The current which flows through a condenser is $I=2\pi fCE$, so that in radio frequency work, even though the capacity is extremely small, large radio frequency current may flow. An inductance coil has capacity to some extent between the turns of wire, which is in the nature of a capacity in parallel with the inductance. Even between the cords of a telephone and the turns of its windings, there is capacitive effect. Small capacitive effects such as those just mentioned are not negligible in radio circuits because they permit the passage of radio frequency current which current increases with increase of the frequency. In ordinary commercial A.C. circuits these effects are usually negligible because the frequencies in use vary from 25 to 60 cycles only.

A variable condenser affects a change of capacity by varying the area common to the two sets of plates.

RESONANCE

32. **SERIES RESONANCE.** Two circuits are said to be in resonance when they have the same natural frequency. Then by coupling one circuit to the other energy may be transferred by small impulses and due to the resonant condition may build up large currents. In a series A.C. circuit we say that a circuit is resonant when the inductance and capacity effects cancel each other, one neutralizes the other, and the current is a maximum, the impedance being a minimum. **This condition of resonance or maximum current exists in a series circuit when the capacitive reactance equals the inductive reactance or** $X_L = X_c$, that is $2\pi f L = \frac{1}{2\pi f C}$. From this we may obtain the resonant frequency or natural frequency of that circuit $f = \frac{1}{2\pi\sqrt{LC}}$ where L = henries, C = farads.

If L is in microhenries and C is in microfarads,

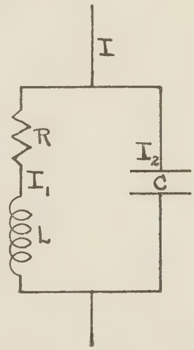
$$f = \frac{10^6}{2\pi\sqrt{LC}} \text{ cycles/ sec.} = \frac{159{,}000}{\sqrt{LC}} \text{ cycles/ sec.} = \frac{159}{\sqrt{LC}} \text{ kilocycles/sec.}$$

In this resonant condition the total reactance equals zero, the impedance equals the resistance and $I = E/R$. If R is zero the current is infinite, but even so-called "pure" inductances and capacities have some resistance which limits the current value.

33. **WAVE LENGTH.** A resonant circuit in radio is used to send out an electromagnetic wave having the same frequency as the circuit and traveling through the ether with a velocity of 3×10^8 meters/sec. From the formula $V = f\lambda$ we may compute the wave length, $\lambda = \frac{V}{f} = 3\times10^8\times2\pi\sqrt{LC}$ where L is in henries, and C is in farads. When L is in microhenries and C is in microfarads the electromagnetic disturbance radiated has a wave length:

$$\lambda = 600\,\pi\sqrt{LC} = 1885\,\sqrt{LC} \text{ meters.}$$

The frequency is fixed for a sending station so that resonance in the receiving circuit is secured by varying L and C. Large changes are made by tapping off a different number of turns from the inductance coils and small changes by varying the position of the plates of a condenser. **This adjustment to the resonant frequency in either sending or receiving is called "tuning."**



34. **PARALLEL RESONANCE.** When an inductance coil of inductance L and resistance R is connected in parallel with a condenser C, the current taken from the line will depend upon the frequency. The circuit is said to be in resonance if the power factor of the line current is unity. That is, the **reactive component of current in the inductance coil must equal the reactive component of current through the condenser.**

$I_1 \sin\theta_1 = I_2 \sin\theta_2 = I_2$. This becomes $\frac{E}{\sqrt{R^2+(2\pi f L)^2}} \times \frac{2\pi f L}{\sqrt{R^2+(2\pi f L)^2}} = E\times2\pi f C$. Then simplifying and solving for the frequency, $f = \frac{1}{2\pi L}\sqrt{\frac{L}{C} - R^2}$.

Thus, where the **parallel** circuit is tuned to the **resonant** frequency a **minimum** line current is produced, the resonant frequency depending on the values of R, L and C. If the value of resistance in the inductance coil is negligible the resonant frequency is the same as for series resonance,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

CHAPTER III

THE SIMPLE OSCILLATING CIRCUIT

1. **EQUATIONS OF OSCILLATING CIRCUIT.** In order to produce an oscillatory current in a circuit containing resistance, inductance and capacity certain conditions must exist. In 1853 Lord Kelvin deduced the mathematical relations that must exist in such a circuit in order that the discharge should be oscillatory. If current is flowing in such a circuit the instantaneous sum of the E.M.F.'s by Kirchhoff's law will equal zero. For the resistance $e = Ri$, for the inductance $e = L\frac{di}{dt}$, for the capacity $e = q/C$. Hence $Ri + L\frac{di}{dt} + q/C = 0$, and as $i = \frac{dq}{dt}$, and $\frac{di}{dt} = \frac{d^2q}{dt^2}$, the equation becomes $\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{q}{LC} = 0$.

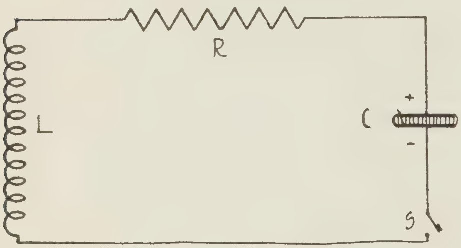


FIG. 1.—Simple Oscillating Circuit.

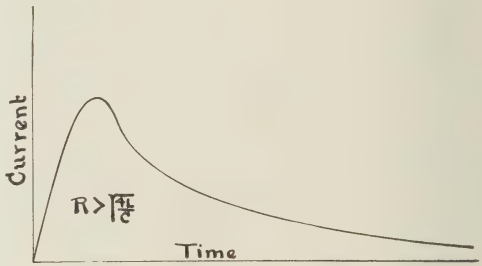


FIG. 2.—Aperiodic Discharge.

2. **APERIODIC CURRENT.** When this differential equation is solved it gives a value for q and hence for i. If the value of R is greater than $\sqrt{\frac{4L}{C}}$ the current is unidirectional (sometimes called aperiodic), it rises to a maximum and then dies away, as in Figure 2.

3. **OSCILLATORY CURRENT.** If the value of R is less than $\sqrt{\frac{4L}{C}}$ the current is oscillatory, that is it varies with a constant period from plus to minus through zero periodically. In this case i the instantaneous value of the current is given by the equation

$$i = \frac{2E}{\sqrt{\frac{4L}{C} - R^2}} \epsilon^{-\frac{Rt}{2L}} \sin \left(\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}\right)t$$

This equation is of the type:

$$i = I_m \sin \omega t.$$

where I_m is the maximum value of the current (amplitude) and $\omega = 2\pi f$, where f is the frequency of oscillation. First it is seen that I_m is of the form $I_m = K\epsilon^{-\alpha t}$ that is, I_m, the amplitude of the vibration, decreases logarithmically from maximum value K to a value of zero after infinite time. Secondly, the vibration is oscillatory with a phase angle ωt or a **frequency**

$$f = \frac{\omega}{2\pi} = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{4L^2}}$$

When these two effects are added together we see that **in a circuit containing R, L and C, with R less than $\sqrt{\frac{4L}{C}}$, an oscillatory current of decreasing amplitude may be set up.**

4. **DAMPED OSCILLATION.** Such a circuit is called an oscillatory circuit. The oscillation is called a **damped oscillation**, that is one with a decreasing amplitude. In circuits used in radio work the value of $R^2/4L^2$ is very small in comparison with $\frac{1}{LC}$ so that the frequency $f = \frac{1}{2\pi\sqrt{LC}}$, L=inductance in henries, C = capacity in farads, f = frequency in cycles/sec. This equation is of fundamental importance in all radio work as it gives the natural frequency or resonant frequency of any radio circuit in terms of the inductance and the capacity. It is seen that this agrees with the definition of resonant frequency in the previous chapter. (Paragraph 32).

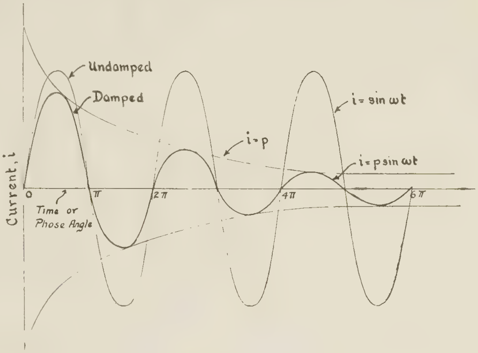


FIG. 3.—Damped Oscillatory Current Curve.

5. **CHANGES IN OSCILLATORY CIRCUIT.** The ideas of the changes in an oscillatory circuit as developed above mathematically may be developed from the consideration of the fundamental operation of capacity and inductance.

(a) **TIME ZERO,** $\omega t = 0°$. Assume that in the circuit of Figure 4 the battery has charged the condenser C so that the upper plate is plus and the lower plate minus, and having done this the battery is removed.

Then at time zero the condenser is charged and the current is zero, the energy of the circuit being in the condenser.

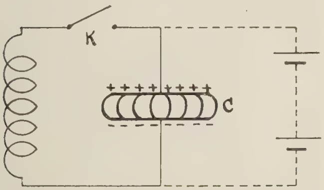


FIG. 4.—Time Zero, $\omega t = 0°$

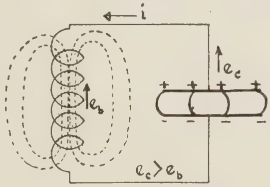


FIG. 5.—Time between 0 and 90°

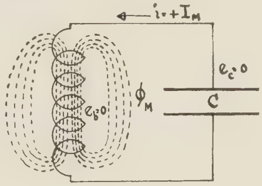


FIG. 6.—Time $= \frac{1}{4f}$ or 90°.

(b) **0° to 90°.** The instant the switch K is closed, or a circuit is formed from the + to the − plate through the inductance, the condenser starts to discharge. Due to the inductance L, a back electromotive force is developed which limits the value of the current, $i = \frac{e_c - e_b}{R}$, but as the condenser discharges the current increases until at time $= \frac{1}{4f}$ or 90° the electromotive force of the condenser equals zero, the current is a maximum, and all the energy of the condenser ($\frac{1}{2}CE^2$) has been transferred to the inductance ($\frac{1}{2}LI^2$). See Figure 6.

(c) **90° to 180°.** The current having been established the inductance tends to maintain it in the same direction. Having reached a maximum the current decreases in the same direction and charges the condenser in the opposite direction. The field of the inductance collapses maintaining

an electromotive force in the same direction as the current until at time $t = \dfrac{1}{2f}$ or 180° the condenser is charged to a value $e_c = -E_m$, the current equals zero and the field of the inductance has totally collapsed, the back electromotive force being equal to E_m. During this interval then the energy of the inductance field has been transferred to the condenser field.

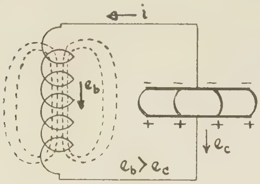


FIG. 7.—Time between 90° and 180°.

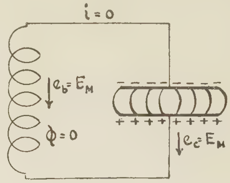


FIG. 8.—Time $t = \frac{1}{2f}$ or 180°.

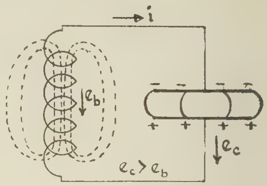


FIG. 9.—Time 180° to 270°.

(d) **180° to 270°.** The current being zero, but the condenser being charged with the bottom plate +, it acts as a battery and drives current through the circuit in the opposite direction, the back electromotive force of the inductance limiting this current. The current reaches a maximum at 270°, at which time the energy and therefore the electromotive force of the condenser has reduced to zero and the back electromotive force of the inductance has reduced to zero. All of the energy has been transferred from the condenser to the inductance.

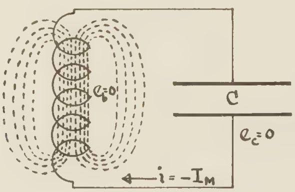


FIG. 10.—$t = \frac{3}{4f}$ or 270°.

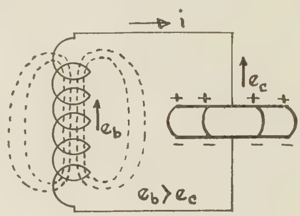


FIG. 11.—270° to 360°.

(e) **270° to 360°.** The inductance tends to maintain the current in the same direction, but this current decreases as the electromotive force of the condenser builds up due to the passage of current, $e = \dfrac{dq}{c} = \dfrac{i\,dt}{c}$ · At 360°, the end of the cycle, the current has again reduced to zero, the condenser has been charged in the original direction, the energy of the inductance has been transferred to the condenser and the circuit is in the original condition (see Figure 4).

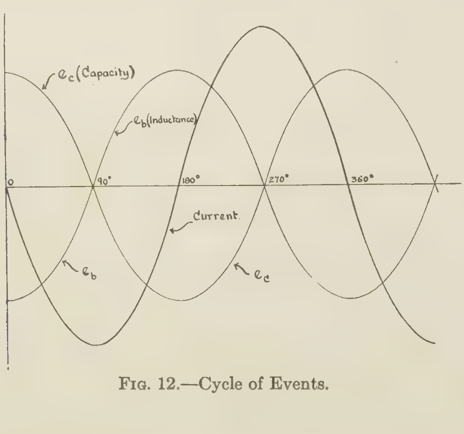


FIG. 12.—Cycle of Events.

6. **GRAPH OF CYCLE.** The whole cycle of events may be shown by a graph as in Figure 12. Every 90° or 1/4 of a period or in a time $\dfrac{1}{4f}$ the energy is transferred from the condenser to the inductance or vice-versa. When the current is zero the back electromotive force of inductance and capacity are both maximum, but in opposite phase, that is, the condenser back electromotive force leads the current 90°, and the inductance back electromotive force lags the current 90°. The inductance tends to maintain a current once started (Lenz's Law), whereas the capacity by building up an opposing electromotive force as the current

changes tends to stop the current. Then having used the current to build up an electromotive force this condenser electromotive force starts the current in the opposite direction.

7. **EFFECT OF RESISTANCE.** The above discussion took no cognizance of the resistance in the circuit. Without any resistance, we would have perpetual motion or oscillation of constant amplitude in such a circuit. But whenever current flows through a resistance, energy is used up in an amount $Ri^2 t$. As this energy is dissipated in heating the resistance it is lost as electrical energy and represents a decrease in the maximum energy in the circuit and therefore a decrease in the amplitude of the current oscillation.

Such an oscillation, in which the amplitude is gradually decreasing due to loss of energy, is called a damped oscillation, and is the type of free oscillation that takes place in a circuit containing L, C, and R. As the amplitude or current decreases the electromotive forces of both condenser and inductance also decrease until they reduce to zero. In the above discussion it may be noted that inductance acts as "electrical inertia," capacity as an "electrical pump", and resistance as "electrical friction."

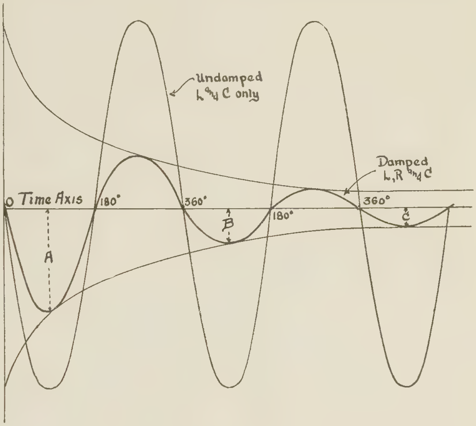


Fig. 13.—Damped and Undamped Oscillations.

8. **DECREMENT.** In an oscillatory circuit containing resistance the amplitude decreases during each cycle. At the instant 90° in Figure 13 if the current has a value A then the energy present in the circuit is in the inductance only and is in amount $\frac{1}{2}LA^2$. During the next cycle an amount of energy $W = \int_0^T Ri^2dt = \frac{RI_m^2 T}{2} = \frac{RI_m^2}{2f}$ is lost in the circuit. The amount of energy remaining in the circuit is then $\frac{1}{2}LB^2$, this having been transferred from inductance to condenser to inductance. The ratio of the energy lost or dissipated in an oscillating circuit in one cycle to the energy actually transferred in that cycle is called the decrement of the circuit. The loss in the circuit $= \frac{1}{2}LA^2 - \frac{1}{2}LB^2 = \frac{RI_m^2}{2f}$; the mean energy present in the circuit $= \frac{1}{2}L\left(\frac{A^2+B^2}{2}\right)$ $= \frac{LI_m^2}{2}$ (as $A = I_m = B$ approximately) and this has been transferred twice during the cycle, i.e. from inductance to condenser and back to inductance. Therefore,

$$\text{Decrement} = \delta = \frac{\frac{RI_m^2}{2f}}{LI_m^2} = \frac{R}{2fL} = \frac{\pi R}{X_L}\left(= \pi R\sqrt{\frac{C}{L}}, \text{ see supplement 5032}\right)$$

It may also be proved that the decrement is the ratio of the amplitude A to the next succeeding amplitude B in terms of the natural logarithm, $\delta = \log_\epsilon \frac{A}{B} = \log_\epsilon \frac{B}{C} = \log_\epsilon \frac{N}{N+1} = \frac{R}{2fL} = \frac{\pi R}{X_L}$.

9. **VALUES OF DECREMENT.** Decrement, therefore, is a term representing the percentage loss in energy, in the square of the amplitude, or in the maximum value of the current squared from one cycle to the next. Ordinary spark sets have a decrement of about 0.1 (10% loss per cycle), and large stations may have a decrement as low as .01. The maximum decrement on which a station may operate is fixed by law, except that for S. O. S. calls a large decrement is allowed in

order to get broad tuning. In an open oscillating circuit, that is, one in which the antenna acts as the capacity, the decrement may be high due to the radiation of the oscillations into space in the form of electromagnetic waves, that is, the value R includes not only the wire resistance, but also ground resistance and radiation losses, that is, R is the **effective** resistance.

10. **UNDAMPED OSCILLATION.** If pulses of energy are supplied at the proper instants to a circuit by a battery, or through a coupling, the oscillations will not decrease in amplitude, but will have a constant value, in which case they are said to be "undamped" or "continuous." See Figure 1 (b) Chapter I. If the energy supplied over-compensates the losses, the amplitude of the oscillations will build up gradually to a greater value than before. The increased power does two things, first, increases the amplitude of the oscillations, and secondly, takes care of increased losses.

11. **RESONANCE IN THE OSCILLATING CIRCUIT.** If as in preceding paragraphs, a condenser discharges through an inductance, an oscillatory current flows in the circuit of frequency $f = \frac{1}{2\pi\sqrt{LC}}\cdot$ This circuit is said to oscillate at its "natural" frequency. If an alternating electromotive force is applied to the circuit the current in the circuit will vary with the frequency of the alternating electromotive force and "forced" oscillations will be set up in the circuit. The maximum current for any particular alternating electromotive force is obtained when the frequency of the electromotive force applied to the circuit (forced) equals the natural frequency of the circuit $f_2 = f_1 = \frac{1}{2\pi\sqrt{LC}}\cdot$ The circuit is then said to be "tuned" or to be in resonance and the current value will be $I = E/R$, this value being reached after several cycles. In order to transmit energy efficiently in radio circuits the various circuits must be tuned:

$$f_1 = f_2 = f_3 \text{ etc., or } L_1 C_1 = L_2 C_2 = L_3 C_3 \text{ etc.}$$

12. **RESONANCE A CONDITION OF "PROPERLY TIMED IMPULSES."** The action of a simple oscillating circuit may be compared to a freely swinging pendulum. One impulse will set the pendulum swinging but with gradually decreasing amplitude until it comes to rest, the rapidity with which the amplitudes die out depending on the friction mechanism. This friction corresponds to the resistance of our simple oscillating circuit. If the friction of the mechanism is excessive, one impulse will move the pendulum, but it stops without oscillating. In our simple oscillating circuit this corresponds to excessive R in which case the circuit is "aperiodic." (See Figure 2).

If small, but properly timed, impulses are given to the pendulum at its natural frequency of oscillation, the oscillations persist at constant amplitude. This is the action in a clock where the wound spring, through the escapement, imparts an impulse to the pendulum at the end of each oscillation.

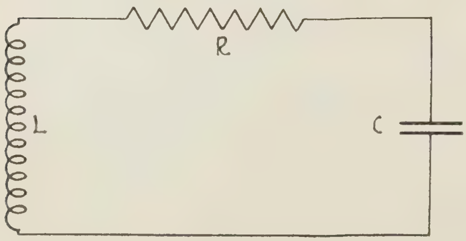


FIG. 14.—Simple "Closed" Oscillating Circuit.

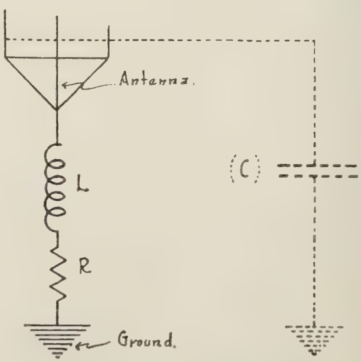


FIG. 15.—"Open" Oscillating Circuit.

If larger, but properly timed, impulses are given to the pendulum at its natural frequency, the amplitude increases until the energy dissipated equals the energy supplied and then the oscillations continue at constant amplitude. In a similar way the current in an oscillating circuit is built up, not instantly, but gradually, to a maximum. This is illustrated by the manner in which a child, with small but **properly timed** impulses, can set a swing in motion and thus build up gradually the oscillations to a very large amplitude.

13. **TYPES OF OSCILLATING CIRCUITS.** Figure 14 shows the conventional diagram for a simple oscillating circuit. This is known also as a "closed" oscillating circuit. If, as in Figure 15, an antenna with distributed capacity and ground connection is substituted for the condenser C, the result is called an "open" oscillating circuit. The capacity effect is shown in dotted lines. The circuit is not actually open but the antenna acts as one plate of a condenser, the ground being the other plate, and an electrical path through the ground is formed for the radio frequency current. The open oscillating circuit or antenna both receives and sends, or radiates, electromagnetic waves better than the closed circuit, which is the reason for the antenna as such. The amplitude of the waves from the open circuit is greater than that from the closed circuit if the same value of current flows in each. Hence the antenna sends or receives more energy than would be the case with a closed oscillating circuit.

14. **COUPLING; TRANSFER OF ENERGY.** These two circuits, the closed and the open, are used together. In order to transfer energy from one to the other they must be "coupled" or a "coupling" must exist between them. There are various types of coupling. Coupling may exist between two closed oscillating circuits. When the energy transfer per cycle is small compared to the energy stored in the primary circuit the coupling is said to be "loose"; when the energy transfer per cycle approaches in value the energy stored in the primary circuit, the coupling is said to be tight.

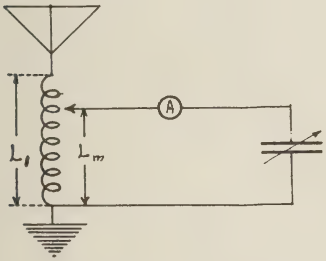


Fig. 16.—Direct (inductive) coupling through L_m. For closest coupling $L_m = L_1$.

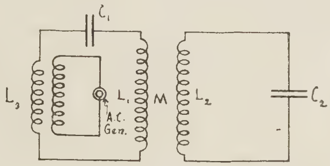


Fig. 17.—Indirect inductive coupling through M. The greater M compared to the total self-inductance of the separate circuits the tighter the coupling. In general use.

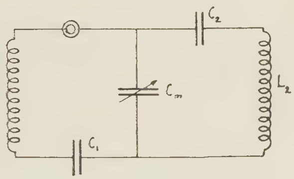


Fig. 18.—Capacitive coupling through C_m. The smaller C_m, the tighter the coupling.

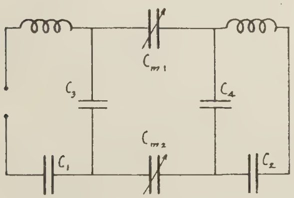


Fig. 19.—Capacitive coupling Coupling through C_{m1} and C_{m2}. Larger values of these capacities give tighter coupling.

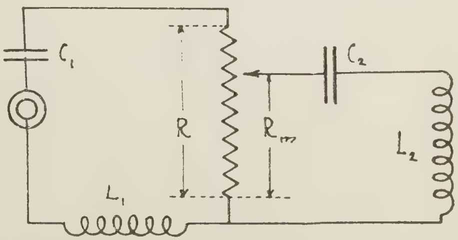


Fig. 20.—Direct (resistance) coupling through R_m. For closest coupling $R_m = R$.

15. **TYPES OF COUPLING.** **Coupling exists whenever resistance, inductance or capacity either in part or in whole is common to two circuits so that there is a transfer of energy between the two circuits.** (Supplement 5012–5030). See Figures 16, 17, 18, 19, and 20. As to whether the coupling is loose or tight depends on the energy transfer. Direct inductive coupling (Figure 16) is tight when the same coil is common to two circuits. Indirect inductive coupling (Figure 17) is tight when the mutual inductance between two coils is high, when the coils are close together and parallel, or wound around the same iron circuit. The tightest inductive coupling is that of a shell or core type transformer when the same flux links both secondary and primary, the leakage flux being relatively small. (See paragraph 21, Chapter II).

In Figure 18 the relation in capacitive coupling may be shown by taking the limiting case. If $C_m = 0$ there is no condenser and the two portions of the circuit are in series, that is the same current flows in each and the coupling is 100%. If a short circuit exists in C_m, the distance between the plates is zero; the capacity equals infinity and L_2 C_2 being short circuited will receive no energy. Hence for this type of coupling the coupling is inversely proportional to the capacity.

For the coupling of Figure 19 the condensers C_{m1}, C_{m2} and C_4 have the same charge induced on them as C_3. As the charge is proportional to the capacity the coupling increases with the capacity.

In resistance couplings the potential drop across the resistance common to both circuits is that which is transferred, hence the greater the common resistance R_m the greater the IR_m drop and the tighter the coupling.

16. **COEFFICIENT OF COUPLING.** The coefficient of coupling, expressed in per cent, shows the closeness of the coupling; the higher the percentage, the closer the coupling. Or generally speaking, the coefficient of coupling is a measure of the percentage of energy transferred from one circuit to the other in one cycle. Close coupling is not always advantageous as will appear later.

For the indirect inductive coupling, which is used most extensively in this country and in our Navy as well, the coefficient is $k = \frac{M}{\sqrt{L_1 L_2}}$ in which M is the mutual inductance between the coils, and L_1 and L_2 are the **total** self-inductances of the respective circuits. These inductances must all be expressed in the same units.

To secure variable inductive coupling various arrangements are used. One coil may telescope with the other such as two hollow cylinders; one may turn inside of the other, as parts of two hollow spheres; the coils may be two flat spirals having a common axis on which they may be moved back and forth; or one of the spirals may be hinged to the other and swing.

17. **THE RESONANCE CURVE; TUNING.** When two circuits are coupled we are particularly interested in the factors which change the current through the secondary circuit. It is found that **the tuning of the secondary, the resistance of the secondary, and the tightness of the coupling** produce important changes in this current. These effects may be shown by a series of experiments and by the curves plotted from these experiments.

These curves are called resonance curves as they show the effect on resonance of various factors. The first of these effects, that of tuning, may be shown by impressing different frequencies upon a fixed secondary circuit.

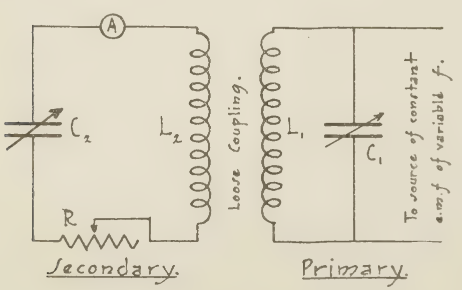


Fig. 21.

Consider the two circuits in Fig. 21, which are **loosely** coupled. The right hand circuit (primary) is a source of constant e.m.f. of variable high frequency which induces high frequency current in the left hand circuit (secondary). Undamped waves are assumed. With condenser C_1 set at its minimum capacity assume that its circuit sends a wave whose frequency is 1500 kcs. It is to be noted that **zero setting** of the variable condenser C_1 **does not mean zero capacity.** Condenser C_2 is set at about mid-position and R is almost all out of the circuit. Read the current as shown

by A. A in practice is a thermogalvanometer whose scale readings are proportional to current **squared.** Now change the setting of C_1, in steps from minimum to maximum capacity, at each step reading A and leaving C_2 and R at their original settings. Knowing L_1 and C_1 we find $f = 1/2\pi\sqrt{L_1C_1} = 1000$ kcs., say.

With values of the secondary current as read from the thermo-galvanometer and the frequencies of oscillations transmitted from the primary plot a curve as shown in Figure 22, curve 1. From this we see that the maximum current through $L_2\,C_2$ (secondary) occurs at a frequency of 1,000 kcs., that is, the secondary is in resonance with the primary at that frequency. The "natural" frequency of the secondary $f = \dfrac{1}{2\pi\sqrt{L_2C_2}}$ is equal to the "forced" frequency from the primary $f_1 = \dfrac{1}{2\pi\sqrt{L_1C_1}}$, and the circuits are tuned to resonance. At this frequency then $L_1C_1 = L_2C_2$, the total reactance of the secondary circuit is zero, and the current is in phase with the electromotive force being limited by the secondary resistance.

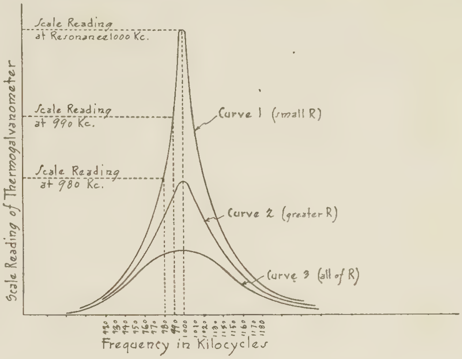


Fig. 22.—Resonance Curves with Different Values of Resistance in Circuit.

The sharpness of the curve shows that the secondary circuit has "**selectivity**" by which is meant that frequencies on either side of the resonant frequency will not have much effect on the oscillating circuit, and hence will have little interference with the desired frequency. Thus at a frequency of 990 kcs., the current in the oscillating circuit is only three-quarters of that at the resonant frequency of 1000 kcs.

18. **EFFECT OF INCREASING RESISTANCE OF SECONDARY OSCILLATING CIRCUIT.** If the experiment is repeated but with more R in the circuit the resulting resonance curve will take the shape shown in Fig. 22, curve 2. Two marked effects are at once apparent; the peak

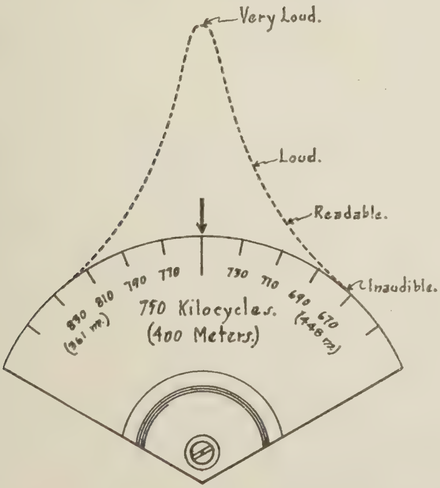


Fig. 23-a Poor Selectivity.

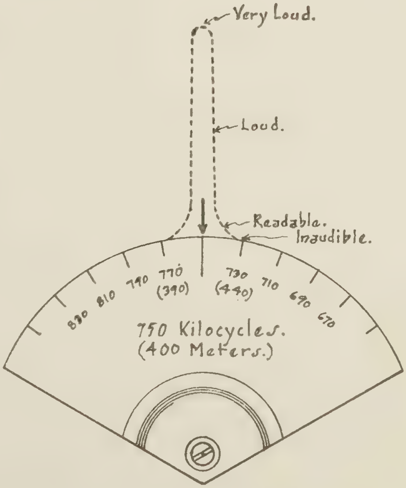


Fig. 23-b. Excellent Selectivity.

Fig. 23.—Selectivity.

has been broadened and the value of the maximum current at resonance is considerably less than before. Curve 2 is constructed for a value of R twice as great as in curve 1.

Increasing the resistance has produced two bad results, viz: maximum current has been reduced and so has the "selectivity." The signal would not only be weaker but there would be greater possibility of interference. Good selectivity and freedom from interference go together.

The relation between these resonance curves and the condenser settings is illustrated well in Figure 23. It will be noted that a small change of setting of the condenser in Fig. 23 b will make the signal inaudible, whereas with the same change in setting of condenser in Fig. 23 a the signal will be still fairly audible. In the first case (b) the selectivity is excellent and we have **sharp** tuning; in the second case (a) we have poor selectivity with **broad** tuning.

19. **EFFECT OF COUPLING ON RESONANCE CURVE.** It was stated previously in determining the resonance curves of Figure 22 that the coupling was "loose" The following experiment with two circuits, inductively coupled, but each circuit separately tuned to the same frequency, will show the different conditions when the coupling is "tight." By means of condensers C_1 and C_2 the circuits are separately tuned to the resonant frequency and the resonance curve of either one may be represented by curve 1, Figure 22. The two circuits are shown in Figure 25, in which L_0, L_1, and C_1 form the primary, and L_2, C_2, and A (ammeter) form the secondary circuit. The primary is subject to an undamped oscillating electromotive force whose frequency may be varied through the resonant frequency. Reading frequencies and currents in the secondary, we plot a resonance curve like Figure 24. The two peaks indicate two values of frequency f' and f'' at which the total reactance is a minimum, one frequency lower, the other higher, than the original resonant frequency, to which each circuit was previously and separately tuned. Readings of primary frequencies and primary currents would give a similar curve. The oscillations are forced at the frequency of the applied electromotive force and there are two frequencies of the applied electromotive force at which the current in either circuit is a maximum, Figure 22, curve 1, is superimposed on Figure 24 for comparison.

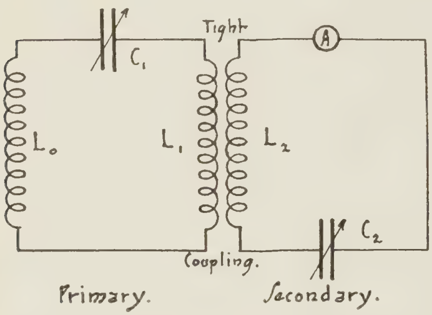


FIG. 25.—Resonant Circuits with "Tight" or "Close" Coupling.

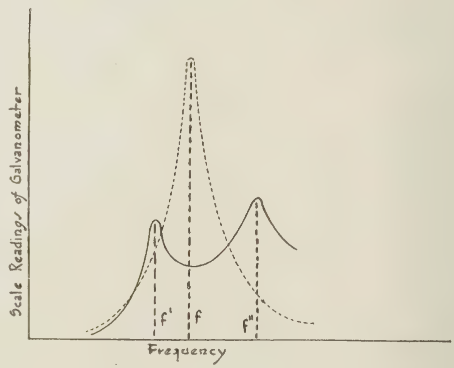


FIG. 24.—Solid Line is Resonance Curve of Circuits in Fig. 25 with Tight Coupling.

When the electromotive force of frequency f is first applied to the primary of the coupled circuits, the currents in the primary and in the secondary are very complicated and consist of free oscillations at the two resonant frequencies (one for each hump), superposed upon the "forced" oscillations of the frequency f. The free oscillations die away quickly and there remain currents of frequency f, in both the primary and secondary.

If f is the frequency to which both of the circuits are tuned, $f = \dfrac{1}{2\pi\sqrt{L_1C_1}} = \dfrac{1}{2\pi\sqrt{L_2C_2}}$, it is

found that the two frequencies which give the maximum currents are dependent on the oupling $f' = \frac{f}{\sqrt{1+K}}$ and $f'' = \frac{f}{\sqrt{1-K}}$ where K is the coefficient of coupling.

That is, if the coupling between the two circuits is reduced ("loosened") and the experiment repeated, the humps will show greater maxima and come closer together and finally, with a still smaller coefficient of coupling, the humps merge in one peak with the one maximum of current; further decrease in coupling simply decreases the secondary current. The original curve of each circuit is as shown in Figure 22, curve 1.

If the resistance of either circuit is increased the peaks become flatter and the current is decreased and the tuning is "broader." (see Figure 22.)

Therefore, selective tuning is impossible with close coupling and selectivity is improved as the coupling is reduced. A change from close coupling to moderately loose coupling should give a great improvement in selectivity. However, it will be found that a change from moderately loose coupling to very loose coupling gives only a small improvement in selectivity. These remarks do not apply to a CW transmitter.

CHAPTER IV

USE OF SIMPLE FREQUENCY METER

1. **SIMPLE FREQUENCY METER.** Instruments, consisting of a combination of an inductance coil and a variable condenser of known constants, which can be used as standards to determine the frequency (or wave length) of radio waves in accordance with the fundamental equation f (in cycles) $= \dfrac{1}{2\pi\sqrt{LC}}$, where L is in henries and C is in farads, are called frequency meters (or wavemeters).

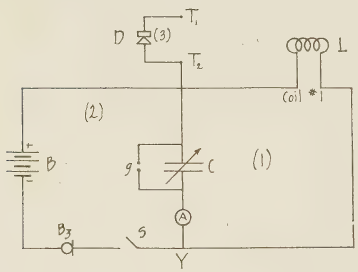


Fig. 1.—Frequency Meter Circuit with "Unilateral" Detector Connection.

2. **ESSENTIAL CIRCUIT.** The frequency meter, which is contained in a box with a hinged or removable cover, consists essentially of a number of fixed inductances (see L, Figure 1) wound on ebonite forms, a calibrated continuously variable condenser, and a device for indicating when the current in the circuit is at maximum. The essential features of the frequency meter circuit of Figure 1, are: (1) a closed simple oscillating circuit consisting of L, C, A, and gap g (the only function of the gap, which has a permanent setting, is to protect the condenser from excessive voltage); (2) the buzzer circuit consisting of switch S, buzzer B_z, battery B and inductance coil L; (3) the circuit containing the indicating devices "A" and "the detector circuit" consisting of the detector "D" and terminals T_1 and T_2, for connecting the telephones. C is a variable condenser whose dial has one-half of its circumference graduated in degrees from 0° to 180°, while the other half is calibrated to read frequency in kilocycles (kcs.). There are two index marks; one at the bottom for degrees, the other at the top for kilocycles. L is a fixed inductance, coil 1 being shown in place. Frequently there are three or more coils to cover a wide range of frequencies with one variable condenser. The inductance coil L fits into a socket and projects from the top of the box. A compartment in the side of the box holds the coils when not in use. The frequency range of the frequency meter is obtained by the combination of the variable condenser and the several coils, the inductance of the latter being adjusted so that a considerable overlap in frequency exists between successive coils.

3. **RESONANCE INDICATING DEVICE.** The indicating instrument may consist of a sensitive high-frequency ammeter or a current squared meter (thermogalvanometer) connected in series with the inductance coil and the condenser, a gas discharge tube containing a rarefied gas, such as neon, connected across the condenser terminals, or a crystal detector and telephone receiver connected unilaterally as in Figure 1 or connected in parallel with the condenser. In Figure 1, A is a hot wire ammeter or thermo element whose accuracy is practically the same over a wide range of frequencies. The thermo element is very delicate and sensitive; therefore, the instruments must be handled very carefully at all times.

4. **INDICATION OF RESONANCE.** Since the inductance and capacity of the frequency meter constitute an oscillatory circuit, this circuit will respond most energetically to a transmitter when the circuit is in resonance with the transmitter, resonance being detected by the indicating device used. In the case of the thermogalvanometer, resonance is indicated when maximum deflection is obtained (*maximum indication being shown when an increase or decrease in capacity causes a decrease in the deflection of the ammeter needle*), with the incandescent bulb when the filament is

brightest, and with the detector and telephones when the signal is loudest. The frequency of the transmitter corresponds to that indicated by the frequency meter when resonance has been obtained as above outlined. The frequency can then be read directly from the calibrated scale or from the frequency curves (condenser settings plotted against frequency) supplied with the frequency meter in accordance with the inductance coil used and the setting of the condenser in degrees. A curve sheet accompanies each frequency meter with as many curves as there are coils and marked "coil 1," "coil 2," etc., which marks are also on the coils.

5. **METHODS OF USING FREQUENCY METER.** There are two general ways of using a frequency meter. In the first method, oscillations of known frequencies are generated in the frequency meter. These are then detected by a detector and telephone in the circuit to be measured. In the second method, the frequency meter is used to measure the frequency of the oscillations produced by some external circuit. If these are free oscillations in the external circuit, this frequency is the resonant frequency of the external circuit. In this second method the oscillations induced in the frequency meter circuit are detected by a detector and head set, or by a thermogalvanometer or hot-wire ammeter. Transfer of power between the frequency meter and an external circuit is **always** accomplished by **inductive** coupling. Metallic connections are never used.

6. **TO MEASURE THE FREQUENCY OF AN OSCILLATING CIRCUIT.** Insert one of the coils in the socket (see that it is all the way home) and S being open, couple the frequency meter to the circuit whose frequency is to be determined, **but with loose coupling**, so as not to burn out the ammeter with excessive current and also so as not to change constants of circuits by tight coupling. The coupling may be varied either by moving the box bodily or by turning L in its socket, the mutual inductance thereby being changed. A good reading is at about the middle of the scale of the ammeter. **Always bear in mind that there may be two resonant frequencies with tight coupling.** Vary C until A indicates maximum reading showing that the frequency meter is tuned to the frequency generated in the other circuit. Note setting of C; kilocycles from upper scale, degrees from lower scale. Wave length λ (in meters) $= \dfrac{3\times 10^5}{f(\text{kilocycles})}$.

7. **USE OF DETECTOR AND TELEPHONES.** The connection of the detector circuit (3 in Figure 1) is called the "unipolar" connection. This method has not as good audibility as some others, such as an inductively coupled detector circuit, but has the distinct advantage that the constants of the frequency meter are not changed appreciably by using the telephones. A telephone with detector (circuit 3) is a more sensitive way of tuning, tuning being accomplished when maximum sound is heard in the phone. The action of the "detector" will be explained under "Receiving apparatus." Circuit 3 works through the distributed capacity effect from T_1 side of the detector to the Y side of the condenser and inductance. In operating the frequency meter be careful not to touch any **metallic part** of the frequency meter as by so doing you add your body capacity to that of the meter.

Frequencies as measured by the frequency meter using the detector and telephone will not agree with those measured when using the thermogalvanometer. This is caused by the addition of a considerable amount of capacity due to the detector. The capacity effect of the detector is more pronounced at the lower settings of the condenser and the actual frequencies will be less than that indicated on the condenser scale.

8. **TO PRODUCE OSCILLATIONS WITH A FREQUENCY METER.** Circuit 2 is connected to circuit 1 by closing switch S which starts buzzer vibrating. Under this condition the frequency meter is called a "driver." With the proper coil at L, and a predetermined setting of C to give the desired frequency, couple the instrument to the circuit whose settings of L and C are to be checked or verified or which is to be calibrated completely. Use as loose a coupling as will permit readings to be taken. Every new setting of C of the frequency meter will generate a new frequency and the L and the C of the other circuit must be changed accordingly.

9. **ACTION OF THE FREQUENCY METER AS A "DRIVER."** With switch S open, the armature of the buzzer is normally in the position of "make." When, therefore, S is closed, three actions

take place: first, a direct current builds up in the circuit consisting of battery B, inductance L, switch S, and buzzer B_2: second, in the branch having C a charging or displacement current which is not continuous flows into the condenser until its potential is equal to the $R\ I$ drop in coil L and as a result the upper plate of C has a positive charge and the lower plate has a negative charge; third, accompanying the flow of current through L, there is a storage of energy in the magnetic field surrounding L. With the constants ordinarily found in a frequency meter the storage of energy in L is **much** greater than in C. In the meantime the buzzer (which operates just as a door bell does) has broken the battery circuit. What occurs at break? When the buzzer circuit is broken the current continues to flow through L and into C thereby charging C, this time positively on the bottom plate. The counter electromotive force built up by C soon stops this current. At the instant the current stops all the energy is then stored in the condenser. The condenser then proceeds to **discharge** through L, thus reëstablishing a current through L opposite to the original direction. The energy is now stored in the inductance. This completes one-half cycle of the oscillation. This oscillation continues with the decreasing amplitude characteristic of a damped oscillation. It will have dropped to negligible amplitude before the buzzer again **makes** contact. Thus it will be seen that each break of the buzzer is followed by one wave train. The degree of damping depends on the decrement of the oscillating circuit.

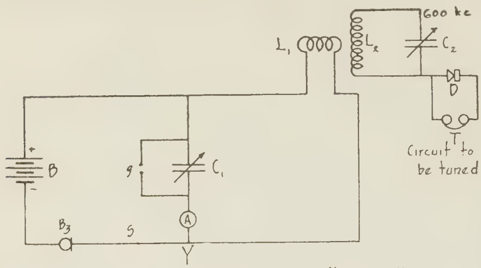


FIG. 2.—Frequency Meter as a "Driver."

10. TO TUNE TRANSMITTING CIRCUIT TO DESIRED FREQUENCY

(a) Insert proper coil in frequency meter (assume coil No. 2 covers a desired frequency of 800 kcs).

(b) Disconnect secondary oscillating (antenna) circuit of transmitter, and loosely couple frequency meter to inductance of primary (closed) oscillating circuit of transmitter.

(c) Close sending key, and measure frequency generated—if this frequency is not covered by coil No. 2 it will be necessary to try other coils until the proper one is found to determine what frequency is present.

(d) Increase or decrease inductance of primary circuit until it is generating the desired frequency (of 800 kcs.) as shown by frequency meter, remembering that frequency varies inversely as inductance.

(e) Release key, remove frequency meter, connect secondary (antenna) circuit and couple **loosely** to primary circuit.

(f) Tune secondary (antenna) circuit to primary, by varying antenna loading inductance until antenna ammeter shows maximum reading (thus indicating maximum radiation at loose coupling when sending key is closed).

(g) Adjust coupling between primary and secondary circuits until maximum radiation is obtained.

(h) Make final test for sharp resonance—with key closed and frequency meter coupled to ground connection of antenna, only **one maximum** reading should be indicated by the meter.

CAUTION.

(1) In coupling frequency meter to any circuit use loose coupling until first reading is obtained and then close the coupling cautiously until the maximum reading of thermo-galvanometer is about on the middle of the scale.

(2) Do not vary the inductive coupling or setting of inductances while the key is held down as the voltage is dangerously high. It is safer practice to take power off the set whenever adjustments are to be changed.

11. TO TUNE RECEIVING CIRCUIT TO DESIRED FREQUENCY

(a) Insert proper coil in frequency meter (assume coil No. 2 for desired frequency of 800 kcs.) and rig meter as a "Driver."

(b) Set frequency meter condenser to desired frequency (800 kcs.) and start buzzer by closing switch S as in Fig. 1.

(c) Couple meter to circuit to be tuned (see Fig. 2). Since meter is a source of very low power, it may be coupled as tightly to the circuit as is consistent with sharp tuning without any danger of burning out the receiver.

(d) Tune receiving circuit to the meter by varying capacity of the former until maximum sound is heard in phones.

NOTE: Many receiving circuits have more than one circuit requiring tuning. In such cases each of these circuits must be separately adjusted, resonance being judged by maximum sound in receiver phones.

12. TO ASCERTAIN FREQUENCY TO WHICH A RECEIVING CIRCUIT HAS BEEN TUNED.

Assuming that a receiving circuit has been tuned to receive a signal from some external source of unknown frequency and it is desired to ascertain this frequency.

(a) Without changing any settings of the receiver circuit, rig meter as a driver, and couple to receiving circuit.

(b) Vary condenser setting of meter to cover all frequencies within its range until response is heard in receiver phones, then read frequency.

NOTE that the thing actually measured is the resonant frequency of the receiver. With receivers using an adjustable coupling this coupling must have been "loose," if an accurate determination is to be made.

13. HETERODYNE FREQUENCY METER.

This type of frequency meter will be described in Chapter XI, paragraphs 25–37 inc.

CHAPTER V

APPARATUS FOR DAMPED WAVE TRANSMISSION

1. The subject of damped waves will be taken up first since the apparatus is simple, rugged, and easily adjusted. Also the earliest development of apparatus used for transmission of radio telegraphy employed damped waves. Spark transmitters are rapidly becoming obsolete, the operating disadvantages being short range for power expended and broadness of tuning, thereby causing considerable interference with frequencies above and below its tuned frequency.

2. In dealing with radio, frequencies of circuits are treated from three different points of view, which will be summarized as follows:

(a) The frequency of the **alternator**, which depends upon the speed and design of the machine, and ranges from 60 to 1000 cycles per second. This frequency is independent of all the radio circuits.

(b) The wave train or **group frequency,** which depends upon the alternator frequency, capacity of the closed circuit condenser, and break down voltage of the spark gap. This frequency in practice, ranges from 120 to 2,000 wave trains, or groups, per second, and determines the tone of the received signal.

(c) The frequency of the **oscillations** in the radio circuits, which depends only on the capacity and inductance of the circuit in question. This is the transmitted frequency, and receiving equipment must be adjusted to be resonant at this frequency in order to receive the transmitted signals.

Reference will be made to these frequencies in the discussions which follow, and care should be taken to distinguish between them as indicated above.

3. **THE SPARK SET.** In par. 24, Chap. I, the statement was made that the first requirement of a radio sending set was that an alternating current oscillating at **radio frequency** must be set up. In the **Spark Set** which is the principal transmitter of damped waves, this is accomplished as follows:

4. **PRODUCTION OF OSCILLATIONS.** The individual trains of damped high frequency waves are produced in the circuit by the discharge of a condenser in a circuit containing inductance as explained in paragraphs 1-10 inc., Chapter III. Instead of switch K of Figure 4, Chapter III, however, a permanent adjustable gap called a "**spark gap**" is substituted in the circuit.

5. **ACTION OF THE SPARK GAP.** This gap has a high resistance while energy is being stored in the condenser and keeps the circuit open until the potential across the condenser is sufficient to "break down" the gap. When this occurs, the resistance of the spark gap is decreased to a very low value due to the fact that the gap becomes a conductor by ionization. While in this condition, free oscillations occur in the circuit until they die out due to the energy being absorbed by the resistance of the circuit. When this happens, the gap becomes deionized and resumes its initial condition of high resistance. The closed circuit is now open so that the condenser may again be charged and the action repeated.

6. **QUENCHING.** The **early** restoration of this non-conducting state is called "Quenching." If the gap did not resume this non-conducting condition, the condenser would not charge again since it would be short circuited by the gap and further oscillations could not be produced.

7. The action of the spark gap then may be considered equivalent to switch K in Figure 4, Chapter III, which is automatically closed when a certain voltage is reached, and similarly opened when the current has decreased to a given value at which the gap is not sufficiently ionized to continue the flow of current.

8. **500 CYCLE SPARK TRANSMITTING SET, USING QUENCHED GAP.** In Figure 1 is shown a typical circuit of a **spark transmitting set,** which consists essentially of three coupled circuits, viz.:

(a) The **Power Circuit** which supplies energy to charge the condenser.

(b) The **Closed Oscillating Circuit** in which the discharge of the condenser sets up free damped oscillations.

(c) The **Antenna Circuit** which converts the oscillations into electromagnetic waves which are radiated off into space.

9. The **Power Circuit** includes a 500 cycle single phase alternator, a transmitting key, a choke coil, the primary and secondary of a step-up closed core transformer, and the transmitting condenser. The power circuit is generally divided into the **Primary Power Circuit** and the **Secondary Power Circuit.**

10. The **Primary Power Circuit** consists of the 500 cycle, 250 volt, single phase alternator, transmitting key, a choke coil, and the primary of a step-up closed core transformer. When the transmitting key is pressed, this circuit supplies the primary of the power transformer with alternating current at $250\sqrt{2}$ peak volts at a frequency of 500 cycles.

11. By employing the dot and dash code the **transmitting key** is used to send the signal. The key is always placed in the low voltage circuit.

12. When the spark gap breaks down, it acts as a momentary short circuit on the alternator through the transformer. To prevent the sudden rush of current which this would cause, an iron core **Choke Coil** whose large inductance opposes a sudden change of current, is placed in the power circuit on the low voltage side.

13. The **Secondary Power Circuit** consists of the secondary of the power transformer and the transmitting condenser. The step-up ratio of the transformer is 1 to 50 and thus alternating current of $12{,}500\sqrt{2}$ peak volts, at a frequency of 500 cycles per second is supplied to the transmitting condenser.

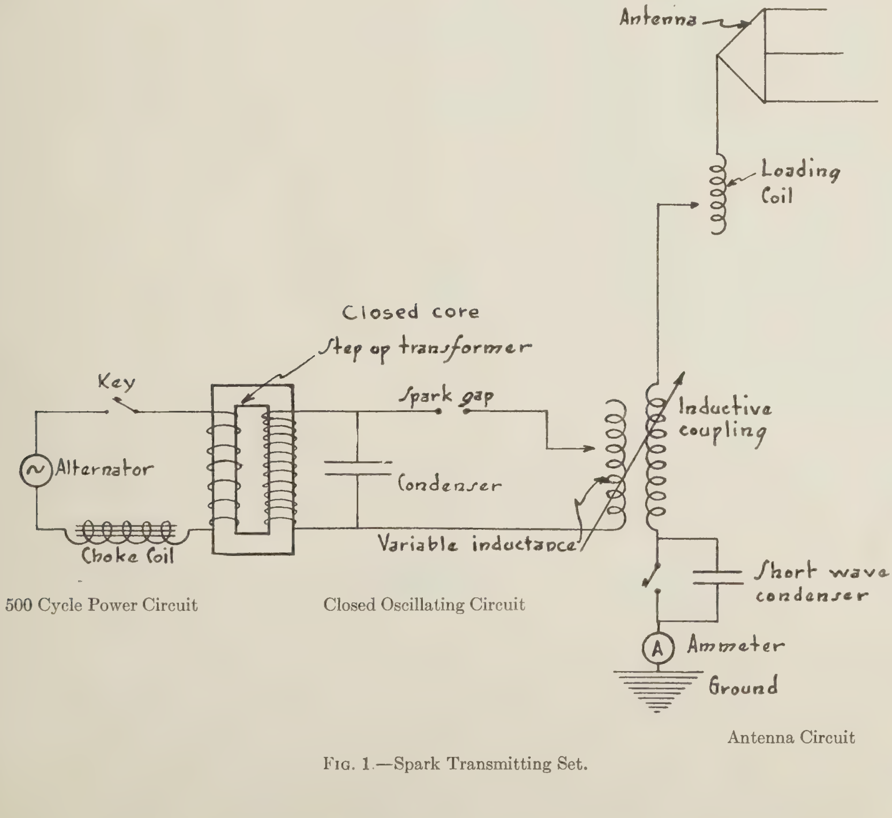


Fig. 1.—Spark Transmitting Set.

14. The leakage reactance of this transformer is very high, and therefore acts as a choke coil to prevent the radio frequency oscillations of the closed oscillating circuit from being fed back to the primary of the power circuit. Sometimes radio frequency choke coils are placed between the condenser terminals and the secondary of the transformer as an additional safeguard.

15. The **CLOSED OSCILLATING CIRCUIT** consists of the transmitting condenser, the quenched spark gap, and that portion of the variable inductance included in the closed circuit. This circuit is supplied with the high voltage ($12{,}500\sqrt{2}$ peak volts) alternating current discharges from the condenser. The position of the spark gap and the condenser may be interchanged without affecting the operation of the circuit.

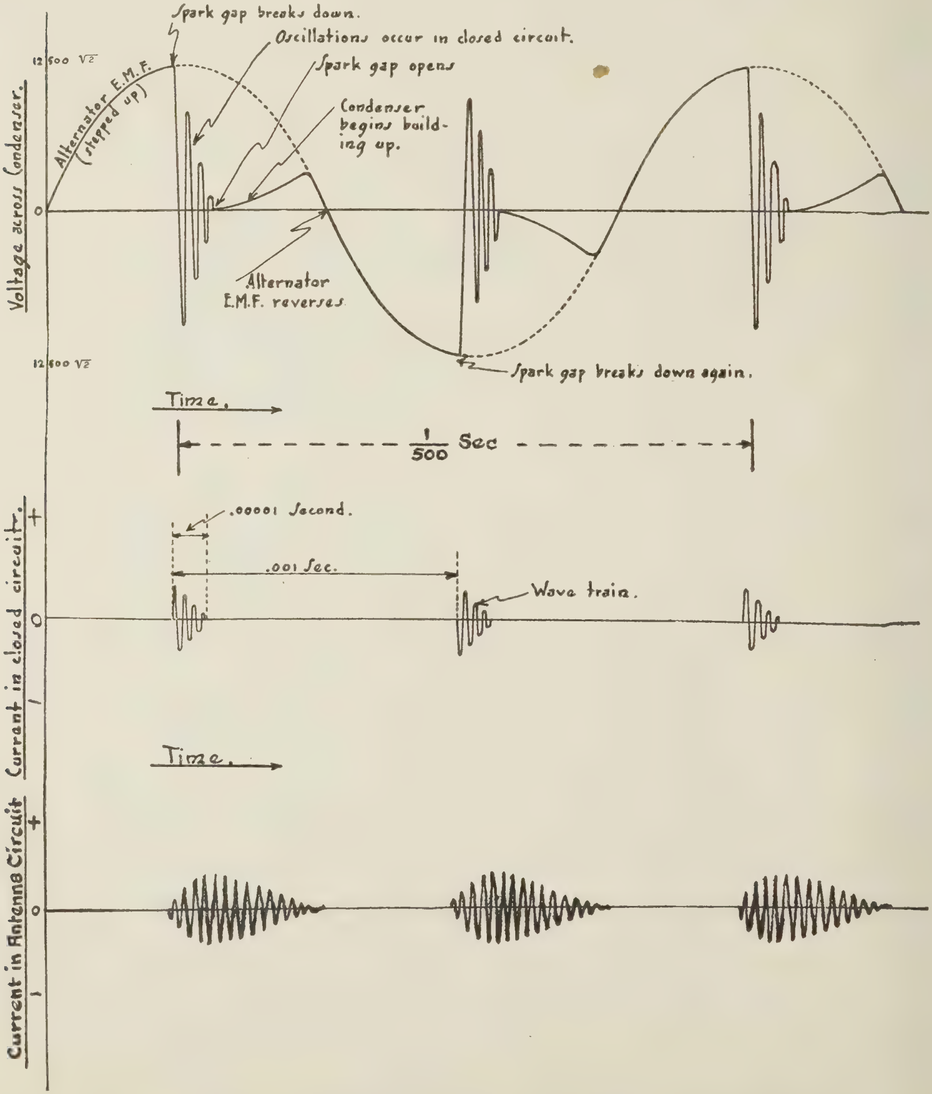


FIG. 2.—Voltage and Current Variation in Closed Circuit Condenser of Spark Transmitter.

16. The inductance of this circuit also acts as the primary of the inductive coupling to the antenna circuit. This coupling is sometimes called a "**radio frequency oscillation transformer.**" It usually consists of two coils of copper ribbon wound in spiral form and arranged so that the mutual inductance may be varied. A **direct** inductive coupling may be used to couple the two circuits.

17. The **ANTENNA CIRCUIT** consists of the antenna, the loading coil, the secondary of the inductive coupling, the short wave condenser with short circuiting switch, hot wire ammeter, and the ground connection.

18. The **LOADING COIL** is an additional variable inductance that can be used for tuning the antenna circuit to low frequencies. The **SHORT WAVE CONDENSER** is an additional capacity in series with the antenna capacity to reduce the total capacity of the circuit and permit tuning to higher frequencies. Connections are so arranged that this condenser can be omitted from the circuit when it is not required.

19. **OPERATION OF THE SET.** When the key is closed, the condenser begins to charge, and after it has been charged up to a voltage sufficient to break down the spark gap, the condenser discharges across it and sets up in the closed circuit a group of damped radio frequency oscillations termed a **wave train.** These radio frequency oscillations are transferred to the antenna circuit through the inductive coupling and set up electromagnetic waves which are radiated into space.

20. The building up of the condenser voltage is best illustrated by a study of the curves representing this condition.

21. Figure 2 shows the order of events in the closed and antenna circuits when the key in Figure 1 is closed and the spark gap is adjusted to break down **once per alternation** at a point just before the maximum voltage is reached. An inspection of these curves shows that the voltage across the condenser builds up following the sine curve of applied electromotive force of the alternator until at about $12{,}500\sqrt{2}$ peak volts, the gap breaks down. The upper curve shows that the 500 cycle alternator of the power circuit charges the condenser **twice during each cycle,** or 1,000 times per second, and the condenser in turn discharges across the gap 1,000 times per second. The number of times per second is called the **spark frequency** or **group frequency** of the transmitter and it governs the pitch of the spark emitted by the transmitter. After each initial discharge across the spark gap from the transmitting condenser in one direction, the inertia of the discharge charges the condenser in the opposite direction. The condenser then discharges again across the gap in the reverse direction.

22. These high frequency discharges of the condenser across the gap and recharging of the condenser after each initial discharge of the condenser across the gap gradually reduce in energy value from maximum to zero due to resistance of the gap and circuit absorbing the energy. These discharges produce high frequency oscillations in the closed oscillating circuit, the frequency of which depends directly upon the value of **capacity** and **inductance** of the circuit. These oscillations continue until the condenser voltage becomes too low to supply sufficient current to keep the gap ionized. The gap becoming deionized resumes its former state of high resistance and allows the condenser to accumulate another charge from the power supply.

23. By this time the voltage of the alternator has fallen as shown by the dotted line to a value too low to break down the gap. Therefore a sufficient charge does not accumulate until the alternator voltage has reversed and has built up almost to its maximum value in the opposite direction. Then the gap breaks down again and the above action is repeated.

24. The high frequency oscillations in the closed oscillating circuit are transferred by electromagnetic induction to the antenna circuit through the inductive coupling in Figure 1. The coupling between coils can be varied by moving one coil closer to or further away from the other. The induced oscillatory current in the antenna is indicated by the bottom curve of Figure 2. This curve shows that the induced oscillatory current increases in amplitude as energy is being transferred from the closed oscillating circuit to the antenna circuit. When this transfer of energy is complete, the antenna oscillates at maximum amplitude, but does not react on the closed oscillating circuit since this circuit is opened by the quenching of the spark in the quenched spark gap. Therefore

the antenna current gradually decreasing in amplitude, continues to oscillate until all of the energy has been radiated in the form of electromagnetic waves or used up in the resistance of the antenna circuit. If the quenched spark gap were not used in the closed oscillating circuit energy would be transferred to and from the antenna circuit until all of the energy has either been radiated into space or else consumed in the resistance of these circuits. Manifestly, the object to be attained is the radiation of the maximum amount of energy with the smallest loss which cannot be accomplished in the latter case.

25. An idea of the comparative duration of the events is shown by the lower part of Fig. 2 where the series of wave trains is represented by the current in the circuit.

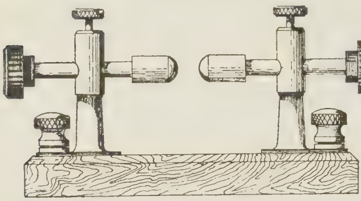


Fig. 3.—Plain Spark Gap.

26. **SPARK GAPS.** Three general types of spark gaps are used, viz.: **Plain, Quenched,** and **Rotary.**

27. The **PLAIN SPARK GAP** is illustrated in Figure 3. This type of gap is not easily deionized (which means that it does not quench rapidly), is noisy in operation, and is now obsolete.

28. **QUENCHED SPARK GAP.** Fig. 4 shows a modern quenched spark gap which consists of several cast circular copper discs about 8″ in diameter, which are grooved as shown. These plates are placed together in series with their silver sparking surfaces adjacent; and separated by mica or fiber washers which insulate the plates and maintain the proper sparking distance as well as make the gap air tight. The groove cut in the surface is to restrict the sparking to the surface provided and prevent sparking around the mica. The sides of the mica washers are coated with shellac and the whole clamped together making air tight sparking chambers. The fins on the periphery of the discs form large radiating surfaces.

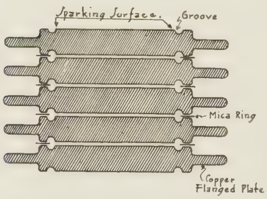


Fig. 4.—Quenched Spark Gap

29. It has been found that a short spark between cool electrodes is quenched very quickly, the air becoming non-conducting as soon as the current falls to a low value. In the quenched gap, instead of one long spark, there are several short sparks in series between the discs, and this fulfills the above condition of rapid quenching. Also the fins mentioned above aid rapid cooling.

30. **ROTARY SPARK GAPS** are designated as synchronous or non-synchronous depending on whether or not they are synchronous with the alternator speed. They consist essentially of two stationary electrodes and a rotating toothed wheel, the teeth of which act in succession as the other electrode. The use of a different tooth for each spark, the rapid opening of the gap, and the fan action of the rotating wheel assist deionization and prevent arcing.

31. The Quenched Gap is the one in general use on spark transmitters. The principal advantage is that a closer coupling may be used between the closed and open circuit and therefore more energy can be radiated from the antenna **since the quenched gap, when properly adjusted, prevents retransfer of energy from the antenna to the closed circuit.**

32. It was explained in paragraph 19 of Chapter III that a close coupling between two circuits tuned to the same frequency was generally objectionable because of the fact that a resonance curve with a broad flat top was produced. Instead of producing, in the secondary, oscillations of the **desired** frequency, oscillations extending **over a band of frequencies** ranging on either side of this frequency would be set up. This effect is due to the transfer of energy back and forth between the two circuits with consequent interference. A loose coupling remedies this to some extent but decreases the amount of energy transferred.

33. When using damped waves, if the energy of the primary circuit could be transferred to the secondary, and then all coupling to the secondary could be removed before any energy could be handed back to the primary, the disadvantages just mentioned would be avoided. In this case, the secondary would be set oscillating at its own natural frequency and the loss of energy in the

primary would be restricted to the short interval during which the primary is acting. By properly choosing the resistance of the secondary, the decrement of the radiated wave may be kept small, and since only a single frequency is radiated, the advantages of close tuning of the receiving circuit can be realized. Such a method of excitation is known as "**Impulse Excitation,**" and is analogous to the mechanical case where a body is struck a single sharp blow, and thereafter executes vibrations, the periods of which depend entirely on the inertia and elasticity constants of the vibrating body itself, and not at all on the nature of the body from which the impulse emanated.

34. This is illustrated in Fig. 5, the upper part showing the quenched primary oscillations in the closed oscillating circuit, and the lower part, the secondary oscillations in the antenna circuit.

35. The decrement of the antenna circuit used in the above case must be much smaller than in one where impulse excitation is not used. This is very desirable as wave trains of high decrement cause "**interference**" with other stations. The lower the decrement, the sharper the possible tuning of the receiving circuit. The U.S. radio laws prohibit the use of a decrement greater than .2.

36. Note that the above decrement refers to the **antenna circuit** which circuit really determines the nature of the radiations. The circuit containing the spark gap will have a varying decrement because the resistance of the spark gap varies with the oscillations.

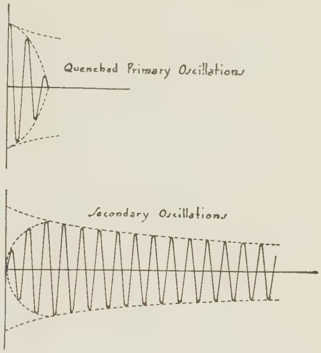


Fig. 5.—Oscillations of Quenched Gap Circuit (Impulse Excitation)

37. **APPLICATION OF DAMPED WAVE TRANSMITTERS.** Damped wave transmitters are rapidly becoming obsolete due to the **interference** they cause in nearby stations as well as the many advantages which continuous wave apparatus has over them. Spark transmitters are being abandoned in the Navy but there are still large numbers of them in use on merchant vessels. The International Radio Convention of Washington, 1927, has ruled that practically all transmission of damped waves shall be forbidden after 1 January 1930.

CHAPTER VI

APPARATUS FOR THE TRANSMISSION OF CONTINUOUS WAVES

ADVANTAGES OF C.W.

1. A continuous wave has been defined in par. 11, Chap. I, and is illustrated in Fig. 1 (b), Chap. I. This type of wave may be compared with the oscillations of a clock pendulum. The main spring, through the escapement, supplies the energy necessary to overcome the losses so that the amplitude of the oscillations of the pendulum, instead of decreasing gradually, is maintained at a constant value. The principal advantages of C.W. are: (1) Radio telephony is made possible. (2) Extremely sharp tuning is obtained, and it is possible for two near-by stations to work on frequencies very close together without interfering with each other; the tuning is, in fact, so sharp that a slight change of adjustment throws a receiving set out of tune and the operator may pass over the correct tuning point by too rapid a movement of the adjusting knobs, particularly with the higher frequencies. (3) Since the oscillations go on continuously instead of only a small fraction of the time, as in the case of damped waves, their amplitudes need not be so great to radiate the same amount of energy, and hence the maximum voltages applied to the transmitting condenser and antenna are lower. The antenna is often the most expensive part of the transmitting station, and since the radiating power of an antenna is limited by the maximum voltage during one impulse, the radiating power of a given antenna is much greater with a generator of continuous waves than with a spark transmitter. (4) The very sensitive method of "beat" reception can be used to advantage, which permits the reception of much weaker signals than could be received by other methods. (5) With damped waves, the pitch or tone of received signals depends wholly upon the number of wave trains per second at the transmitter. With the "beat" method for receiving C.W., the operator controls the tone of the received signal, and this can be varied and made as high as desired to distinguish it from strays and to suit the sensitiveness of the ear and the telephone.

SOURCES OF C.W.

2. **THE ARC CONVERTER.** Probably the first source of C.W. as used in the Navy was the arc converter. The advantages are low initial cost and low cost of maintenance. The disadvantages are that it generates many intermediate frequencies in addition to harmonics. This interference is called "mush" and proved so troublesome that the arc transmitter was withdrawn from all service afloat and is only retained at a few of the high power land stations. Also it is not practical to use the arc converter for radio telephony, nor for the higher radio frequencies, (above 300 kcs.) nor in sizes less than 2 k.w.

3. **THE HIGH FREQUENCY ALTERNATOR.** This, as its name implies, is an alternator of special design to produce radio frequencies as high as 30 kcs. The type was never used in our Navy and was not a commercial success due to its limitation to low radio frequencies, high cost, and critical speed regulation.

4. **THE VACUUM TUBE (abbreviated V.T.).** The description of the V.T. will be taken up in later chapters. For the present, it is only necessary to state that it has replaced the spark transmitter and arc converter in both the Navy and Merchant Marine. It produces C.W. without mush, is readily adapted to use in radio telephony, operates satisfactorily at the highest radio frequencies, and may be designed for as small a power as desired.

THE ARC CONVERTER

5. Before taking up the arc converter proper, it is desirable to consider a plain D.C. arc as shown in Fig. 1. An arc has the peculiar voltage-current relation called a "falling characteristic" as given by the curve of Fig. 2. Suppose the arc is burning across a constant potential. Any small decrease in current decreases the vapor stream between the carbons. The cross-section of the current path has been reduced and hence the resistance of the path has been increased. This will decrease the current still further and continue to do so until the arc is extinguished. On the other hand, any small increase of current will increase the vapor stream between the carbons. The cross-section of the current path has been increased and hence the resistance of the path has been decreased. This will increase the current still further and continue to do so until the arc becomes a short circuit across the line. To overcome this instability of the arc, a resistance called a "**ballasting**" or "**regulating**" resistance is used in series with the arc. Now the potential of the line is consumed in both the arc and the ballasting resistance. An increase of current in the arc produces a greater RI drop in the resistance thereby allowing less drop across the arc. A decrease of current in the arc reduces the RI drop across the resistance thereby permitting a larger part of the potential to act across the arc and bringing the current again to its proper value. The arc converter carries a large current and in order to further reduce the fluctuations of current through the arc, an inductance coil is placed in series also with both the arc and the ballasting resistance.

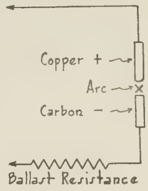


FIG. 1.—Diagram of DC Arc with Ballast Resistance.

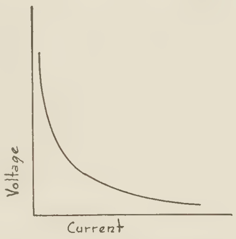


FIG. 2.—Current-Voltage Characteristic of a DC Arc.

PRODUCTION OF CONTINUOUS OSCILLATIONS BY THE ARC

6. The foregoing applies to any D.C. arc such as an arc lamp. In about 1900 it was discovered by Duddell that, if a capacity and an inductance of suitable values in series were shunted around a D.C. arc, as in Fig. 3, oscillations were set up due to the continuous variations of the current through the arc. This was discovered at an audible frequency because the arc emitted a musical note and was known, therefore, as the "singing arc." The frequency of the oscillations produced is governed, however, by the values of inductance and capacity employed to shunt the arc. This led to the development of the arc converter for transmitting continuous radio frequency oscillations.

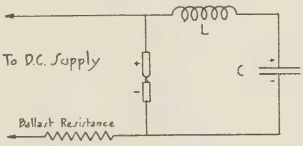


FIG. 3.—Diagram of DC Arc Shunted by an Inductance and a Capacity.

ACTION IN A D.C. ARC SHUNTED WITH L AND C IN SERIES

7. Suppose that the arc is burning steadily with the shunt circuit open. The large inductances in the generator supply line will tend to maintain constant the current supplied by the generator, even if the instantaneous voltage across the arc terminals varies. These inductances should have low distributed capacity. If now the shunt circuit is closed, the condenser C begins charging with its upper plate positive as shown in Fig. 3 and draws current away from the arc, since the current supplied by the generator can not increase suddenly. As the current through the arc decreases, the potential difference of the arc increases because of the "falling characteristic" and helps the charging. The charging continues at an increasing rate until the counter e.m.f. of the condenser equals that applied from the D.C. source. As the charging nears its end, the charging current becomes gradually less, and the current through the arc increases to its normal value, with a corresponding drop in the voltage. The lowering of the voltage across the terminals of the arc assists the condenser to discharge, and the effect of the inductance in the circuit tends to keep the current flowing now causing an increase of arc current above its normal value. At the same time charges are

accumulated on the condenser plates having signs opposite to those which first existed, so that the upper plate of C in Fig. 3 has a negative charge. As this charge with opposite signs now nears its end, the charging current to the right through the arc to the positive side becomes gradually less, and the arc current decreases, causing the voltage to rise. At this point the original cycle starts over again and **thus continuous oscillations take place through the circuit.**

THE POULSEN ARC

8. The foregoing action is that which takes place in what is known as the **Poulsen Arc,** the one which is in general use today. In the Poulsen Arc the discharge current from the condenser must be large enough to extinguish the arc when near the maximum value, but must not be large enough to start an arc again in the direction opposite to that in which the supply direct current is flowing.

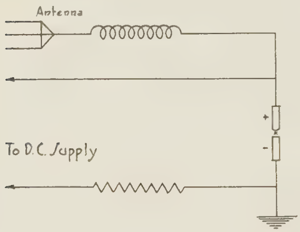


FIG. 4.—Diagram of DC Arc in which Antenna Replaces L and C of Fig. 3.

9. If instead of the shunt circuit around the arc as in Fig. 3 we substitute an antenna, inductance and ground connection as in Fig. 4 we have a means of radiating C.W., the generating action being the same as explained for Fig. 3.

10. The foregoing will set up C.W., but a C.W., however, will not produce an audible signal. By proper variation or interruption of the continuous waves, it is possible to transmit a signal. A key in the D.C. supply circuit or in the antenna circuit would put out the arc. One method is to place the key as in Fig. 5 so that a few turns of the inductance are short-circuited, thus changing the frequency slightly. This is a direct connection, but an inductively connected key would accomplish the same purpose. With the key open a C.W. of frequency f_0 is radiated while with the key closed a C.W. of frequency f_c slightly different from f_0 is radiated. This is apparent from our general formula for frequency, $f = 1/2\pi\sqrt{LC}$, in which L_0 varies slightly from L_c, because some of the inductance has been short-circuited. In practice the receiving station generally tunes to the frequency radiated when the key is **closed.** This method is known as the "compensation method." It has the disadvantage of radiating **two** different frequencies.

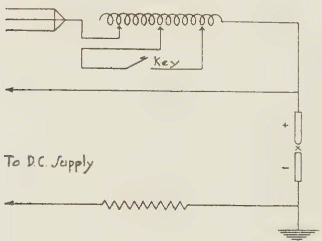


FIG. 5.—Compensation Wave Method of Signalling with CW.

11. To overcome this disadvantage, use is made of the **"Absorption"** or **"Uniwave"** method of arc transmission. A scheme of connection for the Uniwave method is shown in Fig. 6. It will be noted that both the shunt circuit and the antenna-inductance-ground circuit of Figs. 3 and 4 are employed and both are tuned to the same frequency. When the key is depressed the C.W. oscillations are set up in the antenna and radiated therefrom; when the key is released a spring closes contact with the shunt circuit in which the oscillations are then absorbed. Hence the shunt circuit is usually called the absorbing circuit, or "dummy antenna." The type of wave radiated is of a single frequency and somewhat similar to Fig. 1 (c), Chap. I.

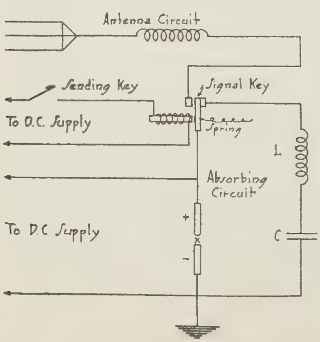


FIG. 6.—Uniwave Method of Signalling with CW.

COMPLETE ARC TRANSMITTER (UNIWAVE METHOD)

12. The circuit for this transmitter is shown in Fig. 7. The apparatus consists essentially of the following: (a) arc chamber and electrodes, (b) field magnets and choke coils, (c) key arrangement for signalling, (d) the absorbing circuit, (e) antenna circuit, (f) D.C. generator and D.C. supply circuit.

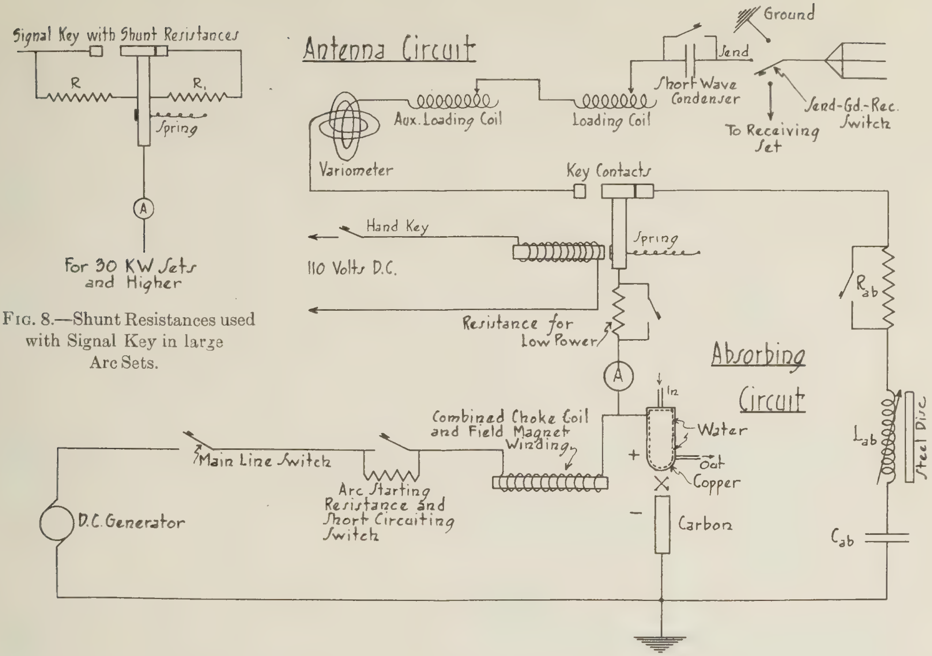


FIG. 8.—Shunt Resistances used with Signal Key in large Arc Sets.

FIG. 7.—Diagram of Complete Arc Transmitter, Uniwave Method.

ARC CHAMBER AND ELECTRODES

13. This chamber is airtight and contains the two electrodes, one of copper and the other of carbon, which are the positive and negative electrodes of the arc, respectively. The large copper electrode is stationary, and has fresh water circulated through it to carry away the heat produced. The electrodes may be either opposite or at right angles to each other. The carbon electrode is rotated by a small motor through proper gears, in order to give an even wear around the carbon tip and thus improve the steadiness of the arc. The carbon electrode is usually connected to the ground on account of simplicity of construction. It is customary to regulate the length of the arc by hand with a feed screw. The carbon is renewed in the same way as that in an arc lamp. The cover of the chamber is always securely closed when in operation.

FIELD MAGNETS AND CHOKE COILS

14. Only one magnet is shown in Fig. 7. This is sometimes divided into two parts, one on each side of the arc. They are in series with each other and the arc and the D.C. supply circuit. There is an iron core for this winding which is closed except for the gap where the arc operates. These windings also serve as **choke coils** both for radio and audio frequency to prevent sudden changes of current in the supply circuit. The magnetic field produced by the coils assists in deionizing the gap between the electrodes when the arc is extinguished momentarily. While the arc is burning, this magnetic field causes the path of the arc to lengthen to one side as in Fig. 9. The longer path gives a steadier arc. When the arc is first ignited it has a path as shown in Fig. 10. As previously stated the magnetic field makes it take the longer path shown in Fig. 9.

FIG. 9.—Path of DC Arc in Magnetic Field.

KEY ARRANGEMENT FOR SIGNALLING

15. As shown in the diagram there are really two keys to make the signal. The hand key operates a solenoid, the latter pulling the middle contact of the relay key from the absorbing circuit to the antenna circuit. The normal position of the middle contact of the relay key is such as to divert the energy of the arc into the absorbing circuit. The contact is held by the spring shown in the figure. The relay key is so arranged by means of spring and screws that contact is made with the antenna circuit before contact with the absorbing circuit is broken, thus preventing opening of the oscillating circuit. For moderate and high power arc sets the relay key is shunted with two resistances as shown in Fig. 8, R for the antenna circuit and R_1 for the absorbing circuit. These resistances, being moderately high, reduce sparking at the contacts. When contact is made with either circuit, it will be noticed that the resistance unit across that contact is short-circuited and therefore the constants of the circuit do not include that resistance.

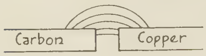


Fig 10.—Path of DC Arc when Started.

THE ABSORBING CIRCUIT

16. This is the same as our shunt circuit around the D.C. arc of paragraph 6 and Fig. 3. There is a steel disc in front of the inductance of this circuit to change the effective resistance of the circuit and this is accomplished by moving the disc toward the inductance to increase the resistance and away from it to decrease the resistance. R_{ab} may be cut out entirely with a short-circuiting switch shown in Fig. 7. C_{ab} is a condenser of fixed capacity.

ANTENNA CIRCUIT

17. This circuit includes ground connection to the carbon electrode, the arc, copper electrode, resistance for low power, radio frequency ammeter "A," the middle contact of signal key, variometer, two loading coils, short wave condenser, and the send-ground-receive switch, and the antenna proper. When using high power the resistance for low power is short-circuited. The variometer is used for changing the frequency over a narrow band in order to attract the attention of the receiving operator. This is because the tuning with a C.W. is so critical that the proper tuning is easily passed over.

D. C. GENERATOR AND D. C. SUPPLY CIRCUIT

18. The voltage supplied to the arc is usually between 200 and 1500 volts. Besides the arc and the field magnets, the latter acting also as choke coils, there are in the D.C. supply circuit, a main line switch and an arc starting resistance. The arc starting resistance is necessary to limit the current when striking the arc. With the arc once started this resistance is cut out either in one step or several steps for large ones.

USE OF HYDROGEN IN ARC CHAMBER

19. The usual practice is to drop alcohol or kerosene from a feeder cup on top of the arc chamber on to the arc whose heat decomposes the liquid, forming hydrogen. The hydrogen assists in the deionization of the gap. The arc burns more steadily in hydrogen than in air.

20. Further, the hydrogen helps to conduct away the heat of the arc. Oxidation of the metal parts of the chamber is prevented with the presence of hydrogen and for a given distance between electrodes the arc will start at a lower voltage in hydrogen than in air. An **EXPLOSION** may occur in the arc chamber if, after the set has been in use, it is opened before the carbon has cooled off. It is also possible that when first starting up, the mixture of air and hydro-carbon vapor may explode. A relief valve in the chamber is provided to release the pressure from the explosion.

SIZES OF ARC CONVERTERS

21. Arc converters are made in sizes from 2 K.W. to 1000 K.W. They were used in our Navy as follows: On shipboard, 2 K.W. to 30 K.W.; shore stations up to 500 K.W., which is the rating of the Annapolis High Power Radio Station. The French station at Bordeaux has a 1000 K.W. set. The construction of larger sets had been contemplated. It is impracticable to construct sets smaller than 2 K.W.

CHAPTER VII

RADIATION OF WAVES

1. The antenna-ground circuit is a simple oscillating circuit in which the antenna and the ground may be thought of as the two plates of a condenser. With this circuit in an oscillating condition the antenna is charged, first positive and then negative with reference to the ground.

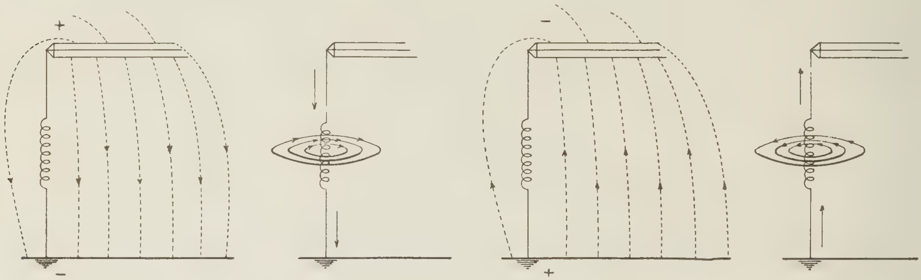


FIG. 1.—Fields Set Up Around an Antenna.

2. The fields set up around the circuit are shown graphically in Figure 1, the four diagrams representing conditions one quarter of a cycle apart. Starting with the antenna charged positively at its maximum in (*a*), there is an electrostatic field set up as shown, similar to that shown across the condenser of Fig. 4, Chapter III. As no current is flowing at that instant, there is no magnetic field in evidence in the circuit.

3. In (*b*), taken a quarter of a cycle later, maximum current is flowing from the antenna downward, the effect being to set up a **magnetic** or **induction** field as shown. The electrostatic field has disappeared since there is no longer a difference of potential between the antenna and the ground.

4. In (*c*) and (*d*), conditions are similar to those in (*a*) and (*b*) but with the directions reversed.

5. Both the electric and magnetic fields represent a state of strain in the ether, the effect being as if particles of the ether were forced out of their natural position against the elastic nature of the ether which tends to bring them back.

6. Energy is required to set up this strain. This energy is supplied by the oscillating current, and as the fields collapse, most of the energy is returned to the circuit. While the circuit is oscillating it will be seen that the energy is transferred alternately back and forth between the electrostatic field and the magnetic field.

7. In Chapter I the statement was made that electro-magnetic waves are set up by a disturbance of an electro-magnetic nature setting the surrounding particles of ether in vibration. Now with current oscillating back and forth in the antenna circuit, the two fields mentioned above are set up and collapse alternately. This produces a displacement of the ether particles that is alternating in direction. Due to the elastic nature of the ether these vibrations of the particles are communicated to adjacent ones and electro-magnetic waves are produced which radiate off into space carrying some of the energy with them. These waves with their self contained energy are usually referred to as the **Radiation Field.**

8. There are then three components which make up the total field around the antenna:

(a) The Electrostatic Field.
(b) The Magnetic or Induction Field.
(c) The Radiation Field.

9. The **ELECTROSTATIC FIELD** is the field usually associated with a **charge** of electricity.

10. The **MAGNETIC** or **INDUCTION FIELD** as it is usually called is associated with the **movement of a charge,** i.e., flow of current. When the current ceases, this field collapses and returns its energy to the circuit. Since the field is never free from the circuit, it is often referred to as the **Stationary Field.**

11. The cross talk between adjacent telephone lines is caused by the induction field. Its action is often spoken of as **"transformer"** action, and it is extensively made use of in transformers of radio sets.

12. The **intensity** of the induction field varies inversely as the square of the distance from the conductor so that the field does not extend very far from the circuit. On this account, it is of very little value for distant communication, though it is used sometimes for short distance signalling. One such application is its use in the channel of New York harbor for transmission of signals from a submerged cable to a ship almost directly over the cable, to aid the ship in keeping in the channel in thick weather.

13. The **RADIATION FIELD** is associated with **acceleration of movement of a charge** of electricity, i.e., with **change of current.** It is the field used to effect the transfer of signals to distant points. It is transmitted by wave motion in the ether as previously explained, the waves being made up of an electric field and a magnetic field, the vibrations of which are in phase but at right angles to each other, both being at right angles to the direction of motion of the wave front.

14. These relations are shown in Fig. 2 where the curve marked E shows the variations in the electric field intensity or displacement, and that marked H, the variations in the magnetic field intensity, the wave moving in the direction shown by V.

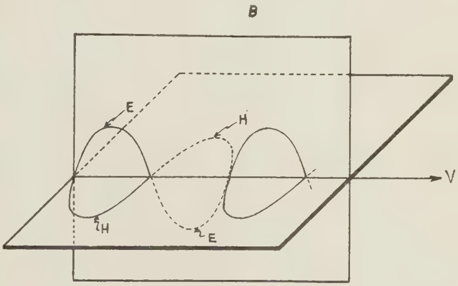


FIG. 2.—Relation Between Components of Electromagnetic Wave.

15. These waves travel through space with the velocity of light, i.e., 300,000,000 meters per second or 186,000 miles per second. Like light waves also, they can be polarized, reflected, or refracted; in fact, they differ from light waves only in wave length. (See Chap. I ¶20–23.)

16. The **ENERGY** required to set up the waves is taken from the current in the antenna, or more directly from the fields which the current produces. This energy is **permanently** removed from the antenna circuit. It does not return to it with the next succeeding alternation as does that of the induction field, but travels along with the wave.

17. The **FREQUENCY** of the wave is the same as that of the oscillating current which produces it. Since the wave length is inversely proportional to the frequency ($f\lambda = 3 \times 10^8$ meters per second) it also follows that the wave length is also determined by the frequency of the current which produces it.

18. The **AMPLITUDE** of a wave is a measure of the amount of energy contained in it. The amplitude varies directly as the rate of change of the current which produces the wave.

19. The **Energy associated with a wave** is directly proportional to the frequency. This explains why radio frequencies have to be used, as it is only when the frequency is high that the radiation field is strong enough for distant communication. Radiation fields are produced at low frequencies, but are too weak to be of value in radio communication. With the ordinary type of antenna, the radiation field using a frequency of 1,500 kcs. would be 25,000 times as strong as the radiation field using the ordinary 60 cycle alternating current.

20. It would appear from the above that the higher the frequencies, the stronger would be the received signals. This would be the case except for the fact that the **absorption** of the radiation field in passing through a medium is greater for the higher frequencies. By **absorption** is meant the loss of energy experienced in passing through an imperfectly conducting medium. It results in reducing

the amplitude of the wave or in "attenuation of the wave." The ideal medium for the propagation of electromagnetic waves would be the perfect dielectric in which there is no absorption. It would be impossible to propagate these waves through a medium which is a perfect conductor. In a perfect conductor there is no elastic opposition to the displacement of electricity and therefore waves would not be transmitted. The magnetic field striking the conductor would induce an electromotive force. Hence a current, which in turn would set up a magnetic field in the opposite direction in accordance with Lenz's law. Since there would be no resistance in a perfect conductor, the result of a wave striking a perfectly conducting sheet would be that the entire energy would be **reflected.** The reflector would have to be large compared to the half wave length. In media other than perfect conductors or perfect dielectrics, there will be some **absorption** and some **reflection,** depending on the conductivity.

21. The waves from a transmitter radiate in all directions into space. That part of the surrounding space which is occupied by the earth (including the sea) constitutes a medium which, although of a relatively low conductivity, is nevertheless sufficiently conducting to produce a very considerable attenuation even in short distances. So that that portion of the wave front in the immediate neighborhood of the surface of the earth (sometimes referred to as the "ground wave"), is useful for communication purposes only for relatively short distances, and for shorter distances the higher the frequency.

22. That part of the space around the transmitter occupied by the atmosphere up to a height of about 100 miles, constitutes a medium of excessively low conductivity—in fact, outside of vacua produced in the laboratory it is as perfect a dielectric as we know—and in consequence, that portion of the wave front whose normals are directed at even small angles away from the earth's surface, travel with almost no attenuation. This portion of the wave system from a transmitter is sometimes called the "sky wave."

23. This "sky wave" portion of the radiated energy would be useless for communication purposes if the earth's atmosphere continued to possess the properties of a perfect dielectric out to the regions of interplanetary space. For in that case, it would continue to be propagated in straight lines away from the earth. There is considerable evidence, however, that at about a height of 100 miles there exists a layer of the atmosphere relatively rich in free electrons. This evidence is drawn partly from auroral phenomena, but more definitely from long distance, and in particular, from short wave radio phenomena. This region, (usually referred to as the Kennelly-Heaviside layer), owes its electrons, in all probability, to solar radiations either ultra-violet or corpuscular, or both, which cannot penetrate deeper into the earth's atmosphere as their energy is all consumed in producing the ionization in that layer. The boundaries of this ionized region cannot be thought of as definite or abrupt, neither should the electronic density throughout its extent be considered uniform. This density should be greatest at some height and fall off to negligible values as we descend or ascend from the maximum position. The effective height of the layer should be expected to vary with conditions affecting the penetrating power of the solar radiations; i.e., with the time of the day, the season of the year, geographical position, etc. There is evidence to show that this effective height may be as low as 60 or 70 miles at midday in summer in the tropics and as high as 500 in the winter Arctic nights.

24. Now, it may be shown that electro-magnetic waves will travel faster through such an ionized medium than in one devoid of free electrons, and that the absorption should be very small. Hence, we should expect that the upper ends of the wave fronts in the radiation from a transmitter would be accelerated relatively to the lower portions moving in the un-ionized lower atmosphere, and that in consequence the wave direction would be continuously changed, and the radiation by a kind of continuous "refraction" returned to the earth, none of it passing on into interplanetary space. If the effect of the layer is formulated in terms of its index of refraction, we can express the results by saying that the wave fronts penetrate the layer with increasing velocity until they reach a height where the electron density is such that the index of refraction becomes zero. After this point has been reached there can be no transfer of energy upward and it is all returned in a downward direction. It also follows from the equations that this "total" refraction will occur at all angles of incidence in

the layer if the wave length is greater than a certain value, but that if the wave length is less than that value, the waves cannot find a region of sufficient electron density to reduce the index of refraction to zero, except for low angle radiation below a certain critical value of the angle of incidence.

This is the best physical picture that has been proposed up to the present of what is taking place in long distance communication. However, for the purpose of practical computations on the ranges to be expected, etc., it is convenient to think of an abrupt **totally reflecting** surface located at such a height that the ray paths at the ends (on the earth) are the same as those given by the "refraction process." This is called the "equivalent reflection" theory, and the relations between the two points of view are as shown in Fig. 3.

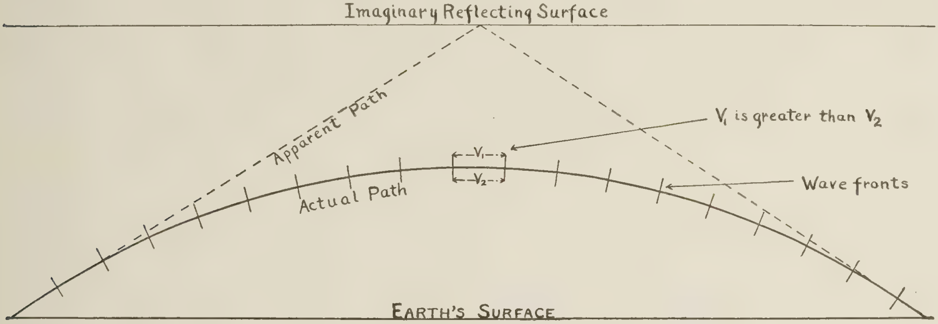


FIG. 3.—Apparent Reflection from Actual Refraction.

25. One other factor affecting the propagation of the "sky wave" remains to be considered. This is the effect of the earth's magnetic field. In general it may be stated that the presence of the magnetic field of the earth has two main effects; first, it splits the beam of radiation in the lower atmosphere into at least two beams, each traveling with a slightly different velocity; i.e., each has a different index of refraction. Second, by providing an opposing force to that present in the wave front, there results a maximum velocity for the electrons in the Kennelly-Heaviside layer at a certain resonant frequency, which according to the best available data is about 1410 kcs. In the neighborhood of this resonant frequency the index of refraction of each component into which the radiation may be split by the action of the earth's magnetic field, varies quite suddenly over very large ranges of values and results in irregularities in the signal received as the result of such refraction.

The first effect mentioned above may result in interference between the transmitted beams at the receiving station if the total distance traversed is not so great that the beams become widely separated, and it is the slight variations in the interference pattern produced and which is caused by variations in the electron density in the Heaviside layer, which produces an important type of fading. This is discussed more in detail in par. 29.

26. The fact mentioned in par. 24 that total reflection will not occur except below a certain critical angle at very short wave lengths, explains the phenomenon of "skipped distances." From the best data obtainable, this phenomenon occurs only for wave lengths less than about 50 meters and for such short waves it is evident that the useful radiation is confined to the cone determined by the tangent to the earth at the transmitter and the critical angle beyond which total reflection does not take place. Consequently, as can be seen in Fig. 4, there may be regions such as AF which will receive no reflected radiation. This fact has received abundant experimental verification and in fact, our most reliable data as to the height of the equivalent totally reflecting plane and the electron density in the Heaviside layer, are derived from measurements of the first "skipped distance."

27. Those fluctuations in intensity of continuous wave signals and the poor modulation and fading of speech signals, which are known under the general name of "fading" find a ready explanation in terms of the refraction ideas explained above. One type of fading (common to all wave lengths) is an intensity fluctuation of relatively long period,—a few seconds in duration. The other type is a

fading at high speed, the signal intensity often varying from full strength to zero at a low audio frequency. This appears as a change in the quality of the heterodyne note when continuous wave signals are being received and as bad distortion in the case of speech signals. In general, for waves longer than 800 meters, high speed fading rarely occurs; in the broadcast band it is noticeable only at intermediate distances and at night. In the region of the short waves below the broadcast band and above those which show a "skip distance" effect the high speed fading is often quite violent at night even quite close to the transmitter. In the range of wave lengths showing skipped distances, the high speed fading is noticeable usually only at the edges of the "skipped regions."

28. Slow speed fading is probably due to a distortion of the received wave fronts by motions of large clouds of the refracting electron medium. On the assumption, which appears reasonable, that the bodily motions of the electron clouds are of the same order of velocity and extent as the air movements and currents in the lower atmosphere, one would expect low frequency fluctuations in a wave refracted through such a medium. For the longer waves, motions of larger electron clouds are necessary to modify the wave front and these on the average would be expected to be slower than in the case of smaller clouds, so that the fading would be slower. Further, for long distances for all wave lengths, the integrated cloud movements and hence, the reflection effects would be expected to average out. This is all in accord with observations.

29. The audio frequency fading on the other hand, is attributable to shifting interference patterns between the various beams into which the transmitted radiation is split by the action of the earth's magnetic field. Considering first the broadcast band, it is to be expected that near the transmitter the ground wave would be of sufficient intensity to drown out any variations contributed by the overhead components. Beyond, say 100 miles, from the transmitter, however, the intensity of the ground wave for these wave lengths becomes comparable with or less than that of the overhead waves, with the result that a complicated interference pattern of various states of polarization and intensities is formed about the receiver. Movements of the electron layer will cause this pattern to shift to and fro, thereby causing the rapid fluctuation of signal intensity. In daylight the electrons gather into low lying clouds of relatively great density gradient so that paths of different overhead rays are relatively close together and the interference pattern becomes broad and hazy. Its movements therefore cause little change in the signals. At night, however, the electrons are more diffuse and their density gradient is much less so that the ray paths are more widely separated. The interference bands are therefore narrower and sharper and the motions of the pattern will cause rapid and violent intensity variations. At distances greater than, say 1500 miles, the ray paths are so long that the interference pattern becomes indistinct in both day and night and the average effects on it of electron cloud movements become less. By similar reasoning, fast fluctuations would not be expected to occur for long waves at any place because in the near distances the ground wave is strong, and in the far distances the interference pattern is diffuse. In the case of those waves showing the skipped distance effect, it is easily seen that the possibilities for sharp interference exist only on the edges of the skipped zones. In the band of frequencies between the broadcast band and that showing skipped distances, rapid fading occurs at distances as small as 5 miles from the transmitter. This means that for these waves at this distance the overhead components reach the receiver with an intensity comparable with that of the ground wave, even after traveling 100 miles or so up into the upper atmosphere and being reflected back at nearly normal incidence. It also implies that the ground wave is attenuated much more rapidly than in the case of the waves of greater wave length.

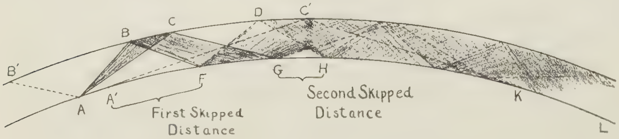


Fig. 4. Paths taken by radio rays in traveling around the earth.

The various components of the wave besides interfering also may arrive at a receiver at different times because of the different paths which they traverse. This will have no effect on the interference patterns just discussed if the wave trains

are long, as in continuous wave signals, but will become an additional cause of distortion in the case of short wave trains such as the modulated waves of speech signals.

30. In the transmission of signals over very great distances it can be seen from such a diagram as that of Fig. 4, that we have to do both with reflections from the Kennelly-Heaviside layer and from the surface of the earth, thus if in that figure the rays from the transmitter A are confined to the space BAC, the upper limiting ray AB descends to F where AF* is the first skipped region, is reflected back to D and down again to the earth at H, etc. continuing around by successive reflections. The lower limiting ray may be tangent to the earth as shown by AC′ or may be inclined at an angle to the horizontal in the manner of AC. In the latter case if $AG<AH$ where $AH=2AF$ there exists a second smaller skipped region GH. These are possible but not so probable because they become successively smaller and more ill defined.

If the bundle of transmitted rays is limited on its lower side by the tangent ray AC′, which is reflected to the earth again at K, the region KL can be reached by a ray from A only after at least one ground reflection and two layer reflections. With a layer height of 150 miles AK is 2000 miles. The region FK on the other hand, can be reached by a ray which has experienced only one layer reflection and no ground reflection. Therefore, because the ground reflecting power may vary with locality one might expect possibilities of poorer signals in the region KL than in the region FK quite apart from the difference in remoteness; or more graphically, the poor reception at a station 5000 miles away may be due to a forest 2500 miles away.

In general, for the shorter waves, observations by many receiving stations in the United States indicate better signal reception in the region extending from the first skipped zone to 2000 miles than in the region between 2000 and 4000 miles where at least one earth reflection is involved. At greater distances however, from 5000 to 10,000 miles the short wave signals are very reliable—much more so than in the 2000 to 4000 mile zone. This is to be expected because with increase of distance there are a greater number of possible ray paths connecting the transmitter and receiver so that a local disturbance such as poor earth reflection of any one ray will have small influence on the signal. One might expect the inverse distance law of signal intensity to hold approximately in this region for the short waves. At the antipodes of the earth there is a concentration of ray paths and a corresponding increase in signal strength. This has been frequently observed.

31. **Static, Atmospherics, and Strays** are the names given to electrical disturbances which give rise to irregular noises heard in telephone receivers. They are most common in summer and are particularly severe in the neighborhood of thunder-storms. Their cause is undoubtedly variations in the electrical state of the lower atmosphere and much work being done at the present time tends to connect them with the larger storm movements of the earth's atmosphere. Although many schemes have been tried it cannot be said that there has been any considerable degree of success attained in the elimination of these effects; i.e. no scheme that is universally applicable or considered practicable for naval use.

32. The outline of the theory of wave propagation around the earth by continuous refraction or equivalent reflection which has been given above, has been abstracted from a paper published in the Physical Review, Volume 27, No. 2, February 1926, by Drs. A. Hoyt Taylor and E. O. Hulbert of the Naval Research Laboratory, and the complete paper should be consulted by anyone who desires to pursue the subject further.

* Only that part of the distance, AF, from where the ground wave has been absorbed on to F is the first skipped distance, say from A′ to F. The distance AA′, however, is usually small in comparison with AF.

It must be remembered that the transmitter at A sends out waves in all directions and does not confine its radiation to the space BAC. BAC contains the only useful radiation. That sent out in space marked by the spherical cone or solid angle BAB′ is lost into space, not being reflected, or rather refracted, back to the earth. Likewise the radiation below the angle formed by CA and the tangent to the earth at A is lost. The angles CAF and BAF vary with the frequency and the height of the Heavyside layer.

CHAPTER VIII

RECEIVING APPARATUS

GENERAL

1. Receiving sets are divided into two general classes: (a)(1) those for the reception of damped waves and (2) continuous waves modulated at an audible frequency; (b) those suitable for the reception of unmodulated continuous waves. Some sets receive all three types of waves mentioned.

E.M.F. INDUCED IN ANTENNA

2. The antenna at the sending station radiates a radio frequency electromagnetic wave. A small part of this is absorbed by the antenna at the receiving station. The wave has a magnetic field which moves across or sweeps through the conductors of the receiving antenna. When a conductor and a magnetic field have relative motion we know that an e.m.f. is induced in the conductor which, in this case, is the receiving antenna. The oscillations of the induced voltage may have very small amplitudes, but when the receiving antenna is tuned to the incoming wave these small induced voltages will gradually build up appreciable oscillations of current in the receiving antenna.

METHOD OF RECEPTION

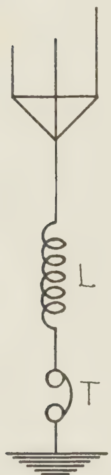


Fig. 1.—Telephone in Receiving Antenna.

3. If a telephone receiver were put in the receiving antenna as in Fig. 1 to obtain an indication of an incoming continuous wave, no sound would be heard for two reasons, viz: first, the oscillations of current are at a radio frequency and the diaphragm of the phone, due to its inertia, would have difficulty in following the oscillations; second, if it could follow the radio frequency oscillations the sound would not be within the range of audibility because of the radio frequency. Now if the same connection be used to receive a continuous wave modulated at audio frequency, no sound will be heard. While the conditions are substantially the same as above, it should be noticed that, although the small current passes through the phone and produces a varying series of impulses on the diaphragm, following an impulse in one direction there is substantially an equal impulse in the opposite direction. These two impulses are so close together that the diaphragm has practically no resultant motion. With the modulated C.W. it may be seen that suppressing the impulses of current in one direction would allow those in the opposite direction to have a cumulative action and thus cause the diaphragm to move in a manner following the modulation of the C.W. So far as the above is concerned the action of a damped wave is the same as that of a modulated wave. It is thus necessary to break up the radio frequency oscillations into audio frequency groups to which the telephone diaphragm will respond. This is accomplished by means of what is known as a "detector" or "rectifier" in conjunction with the telephone receiver. The action of the "rectifier" will now be described.

CRYSTAL DETECTORS

4. A device or substance which offers high resistance to current flow in one direction and low resistance to current flow in the opposite direction is said to possess "asymmetrical" resistance, or has "unilateral" conductivity. Such a device, to be studied later, is the vacuum tube. Of the substances which have the above property, there are many crystals among which may be mentioned

carborundum, galena, molybdenite, iron pyrites, bornite, chalcopyrite, and zincite. Generally a sharp pointed wire is used to make contact with the crystal and the best operating spot is found by trial. The action of a crystal rectifier is understood best by a study of its **"characteristic curve."**

5. One circuit to obtain such a curve is shown in Fig. 2. This scheme is called a potentiometer connection. O is a fixed point of connection to the middle of the resistance R_1 R_2. The voltage applied to the rectifier is the drop across R which is the resistance included between the point O and the moving contact A_1. If A_1 moves to the right of O the potential across the detector has been reversed. Thus we are able to find the current through the crystal for positive and negative drops by reading the D.C. ammeter A. If A_1 coincides with O, the drop, of course, is zero which is the starting point.

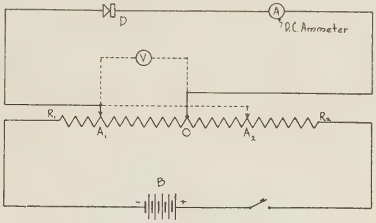


FIG. 2.—Circuit for Determining Characteristic Curve of a Crystal Rectifier.

6. Plotting the readings of voltmeter V and ammeter A for steps of resistance on each side of O, we secure a curve such as that in Fig. 3, which is the "characteristic curve" of a carborundum crystal using a fine steel wire for contact. A study of the curve shows that, except for small voltages, the currents for positive values of voltage are much greater than for equal negative voltages. For any value of voltage above "e" we see that the current variation is the greatest and therefore it is desirable to operate the crystal at that point. This may be accomplished by the circuit of Fig. 4.

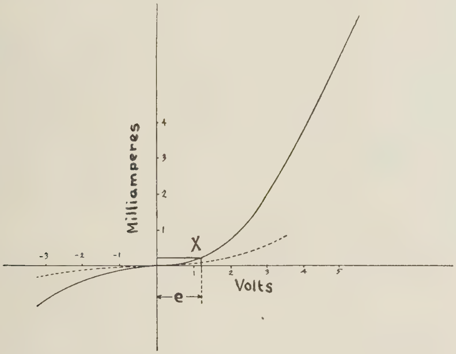


FIG. 3.—Characteristic Curve of Carborundum Crystal rectifier with fine steel wire for Contact.

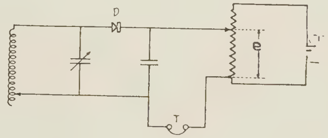
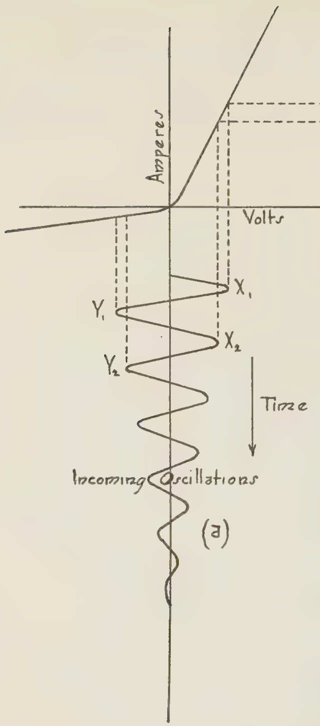


FIG. 4.—Circuit for Operating Crystal Rectifier at that point on the Characteristic Curve where curve turns up sharply.

7. A battery with potentiometer connection is employed to provide an adjustable voltage equal to "e" across the crystal through the inductance and the telephone which form a continuous path. This has the effect of moving the voltage axis in Fig. 3 to the right by an amount equal to "e." The voltage in the antenna, therefore, may be lower than before and still there will be an appreciable current through the telephone. The sensitiveness of the crystal has been increased. The best position of the moving contact of the potentiometer in Fig. 4 is that which gives the loudest response in the phone. This arrangement is not necessary if the characteristic curve of the crystal has its maximum curvature near the origin. It is well to remember, however, that not all crystals have this characteristic.

EFFECT ON RECTIFIER OF DAMPED E.M.F.

8. If a damped wave of e.m.f. such as is produced by a spark transmitter is impressed on the crystal the resulting current in the telephone is shown graphically in Fig. 5. For positive e.m.f, the current



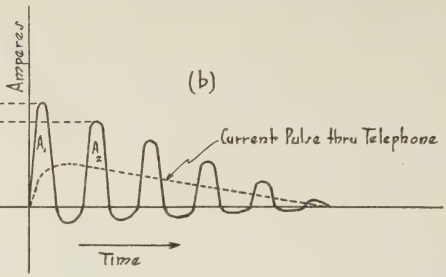


FIG. 5.—Action of Crystal Rectifier and Telephone when Subjected to Damped Wave Train.

loops in curve (*b*) are large, whereas for negative values tht loops are small and tbe net result is a pulse of currene through the phone as shown by the dotted curve in (*b*), to which the diaphragm responds, and there is thus a deflection of the diaphragm for each wave train. It is found that the cumulative effect of one group or train of waves pulls the telephone diaphragm away from its neutral position. The radio frequency oscillations of the rectified waves do not pass through the telephone on account of the latter's large inductance. But the low frequency current of a rectified wave train gives one pull or deflection of the diaphragm. The frequency of the wave trains has been shown to depend on the spark frequency of the transmitter and is usually 1,000. Hence the sound in the phone has a frequency of 1,000 and is audible. If the spark frequency were any other **audible** frequency it would likewise be heard in the telephone. Thus we have a means of breaking up radio frequency oscillations into audio frequency groups, these latter producing an **audible** response in the telephone.

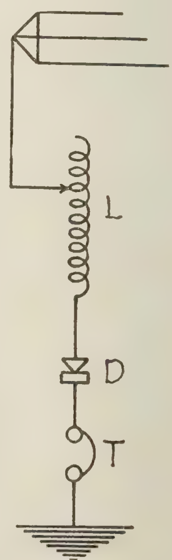


FIG. 6.—Simple Receiving Circuit for Reception of Damped Waves.

CONSTRUCTION OF TELEPHONE RECEIVER

9. The receiver usually employed is known as the "watch case" type because it is contained in a small, flat, compact case. It consists essentially of a steel diaphragm, a permanent magnet which maintains a steady pull on the diaphragm, and two soft iron cores surrounded by the windings which carry the current. The flux of the permanent magnet is greater than that produced by the signal current so that maximum deflection of the diaphragm is possible without distorsional effects, and the diaphragm vibrations are proportional to the current amplitudes. The soft cores are wound with as many as 10,000 turns of No. 40 (or smaller) copper wire. The D. C. resistance of such a winding would be of the order of 1000 ohms; its effective A.C. resistance will vary with the frequency. The **impedances** at various frequencies would be about as follows: 3000 ohms at 400 cycles, 4000 ohms at 800 cycles, 4500 ohms at 1000 cycles.

10. These figures, together with the low value of voltage oscillations in the receiving antenna, account for the telephone current being measured in **micro-amperes.** Two of these receivers are used in series, one for each ear, with a flat, steel spring over the head to hold them securely. They should be handled carefully at all times as they are delicate and expensive.

TYPICAL CIRCUIT FOR RECEPTION OF DAMPED WAVES

11. The simplest circuit for such reception is represented in Fig. 6. This is not satisfactory for the reason that the resistance of the telephone is very high, and the current oscillations would be very feeble and the signal very weak. The practical circuit is shown in Fig. 7. The antenna circuit is familiar being identical with the one used in the spark transmitter in Fig. 1, Chap. V.

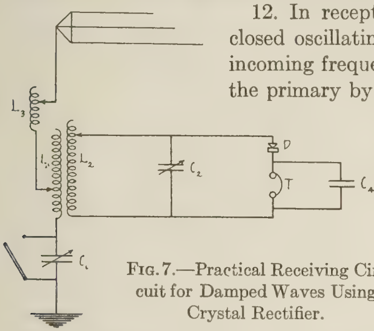


FIG. 7.—Practical Receiving Circuit for Damped Waves Using Crystal Rectifier.

12. In reception, the **antenna** is designated as the **primary,** and the closed oscillating circuit as the secondary. The primary is tuned to the incoming frequency by means of L_1 or C_1. The secondary is then tuned to the primary by varying L_2 or C_2 for the loudest sound in the telephone T. D is the crystal rectifier. The coupling is varied by moving the coil L_2 with respect to coil L_1. C_4 is a "bridging condenser" of fixed capacity in shunt with the telephone. It provides a low impedance path for the radio frequency component of the rectified current and with the charge accumulated during the passage of a wave train, it discharges through the phone at audio frequency assisting the rectified current and giving a louder signal. The distributed capacity effect between the cords and windings of the telephone is not usually sufficiently great to give the best result, hence the use of a concentrated capacity C_4.

13. The cycle of events may then be shown graphically by the curves of Fig. 8.

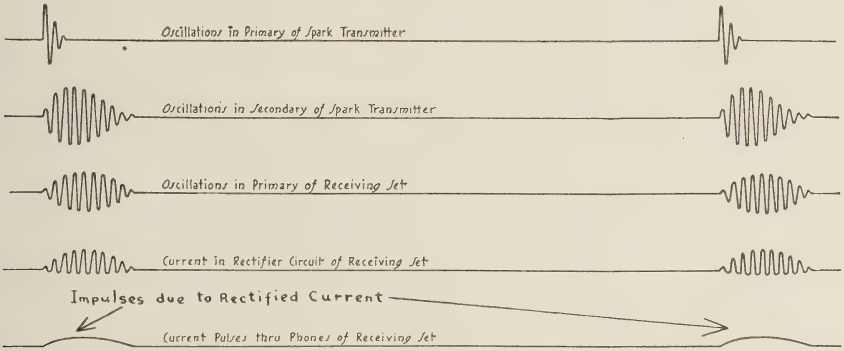


FIG. 8.—Cycle of Events in Reception of Damped Waves.

RECEPTION OF C.W.

14. The reception of C.W. **without any interruption or modulation** would give **no audible signal.** This is apparent by an inspection of Fig. 9. Curve (a) shows a C.W. without interruption or modulation of any kind. Curve (b) shows the rectified C.W. and (c) is the current through the phone. The last curve shows a **steady** telephone current. There would be no vibrations of the telephone diaphragm with such a current. There would be merely a click when the current started and another click when it ceased; which affords no method of signalling. The diaphragm deflects a certain distance and there it remains. It is exactly as if a battery were connected to the phone and a signal expected to be heard by such a **steady** flow of current. There must be some **audio frequency interruption,** or **modulation at audio frequency.**

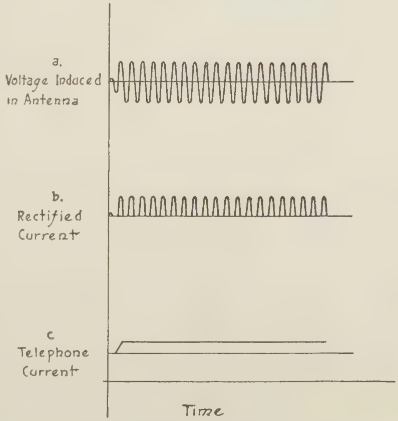


FIG. 9.—Effect of Unmodulated C.W. on Telephone.

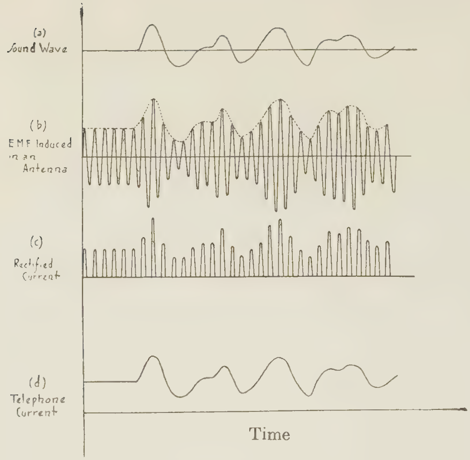


Fig. 10.—Modulated Continuous Waves.

RECEPTION OF MODULATED C.W.

15. Referring to Fig. 10, curve (*a*) is a sound wave produced by the voice or an instrument. It has audio frequency variations. This wave is made to produce corresponding changes in amplitude of a C.W. of radio frequency as shown in curve (*b*). How this is accomplished is explained later under the radio telephone. Curev (*b*) is a **modulated** C.W. Curve (*c*) shows the result of the rectifier action and curve (*d*) shows the current through the telephone which, having the same audio frequency variations as the original sound wave, causes the diaphragm to vibrate in a corresponding manner thus reproducing the voice or the notes of the instrument. The circuit for the reception of modulated C.W. is the same as that for the spark reception as in Fig. 7, that is, using an antenna and a closed oscillating circuit **with rectifier and telephone.** For perfect reproduction the envelope of the modulated wave must be a duplicate of the original wave. Both curve (*a*) and curve (*b*) of Fig. 10 are produced at the transmitting station.

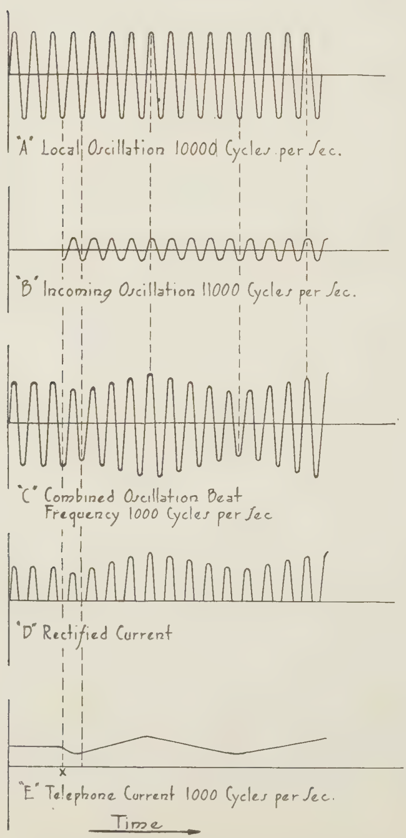


Fig. 11.—Illustrating "Beats" in Autodyne or Heterodyne Reception.

BEAT RECEPTION

16. It was stated in par. 14 that a C.W. of itself cannot be made to produce an audible note in a phone. The effect of such a wave on a telephone is illustrated in Fig. 9. If **another** C.W. of a **frequency** slightly **different** from that of the incoming C.W. is superposed on or combined with the latter at the receiving station, there will be produced the phenomenon of "beats." This method of "beat reception" is similar to the phenomenon of "beats" in the study of sound. The combination of the two C.W.'s results in a current which alternately increases and decreases, depending on whether the component oscillations, at any instant, are in or out of phase. When in phase the currents are additive and the maximum value occurs; when out of phase 180° the currents are subtractive and the resultant value is a minimum. The number of "beats" per second equals the difference between the frequencies of the two C.W's.

17. **Beat reception** is illustrated in Fig. 11. The difference between the frequencies of the incoming C.W. and the C.W. superposed at receiving station must be an **audio frequency.** For example, if the incoming radio frequency is 800 kcs., the frequency of oscillations generated at the receiving station may be 799 kcs., or 801 kcs. In either case the **audible beat frequency** is the difference, or 1000 cycles which is the pitch of the note heard in the telephone.

18. A vacuum tube (abbreviated V.T.) is the source of the locally generated C.W. If the same vacuum tube which rectifies the current also generates the local C.W., the method of beat reception is called "autodyne" reception; if a separate and distinct vacuum tube, besides the one used for rectifying, is employed to generate the local C.W., the reception is known as the "heterodyne" method. A circuit for heterodyne reception is shown in Figure 12. A circuit for autodyne reception is shown in Figure 1, Chap. XI. Both of these methods of beat reception will be discussed in Chap. XI. The reduction from the incoming radio frequency to an audio frequency may take place in more than one step, in which case the intermediate steps may utilize lower radio frequencies. It is to be noted that a detector is required for **each** step in this reduction of frequency. When the reduction takes place in steps as mentioned above, the method of beat reception is called the "superheterodyne" method.

19. If the incoming C.W. of frequency f_1 has an amplitude of 1, and the locally generated C.W. of frequency f_2 has an amplitude of 4, then the resultant current, when the two C.W.'s. are combined to produce "beats," has an amplitude which varies between $4+1=5$ and $4-1=3$, or through a range equal to $5-3=2$. This resultant current passes through its maximum value once for every beat, or the number of times per second equals the difference in frequencies, f_1-f_2.

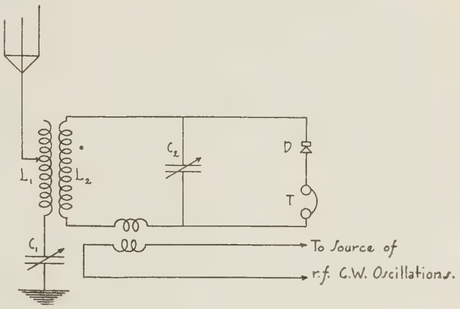


Fig. 12.—Circuit for Heterodyne Reception.

20. If the amplitude of the incoming wave is reduced to 1/2, and the local C.W. maintains the same amplitude as before, the resultant beat current varies between $4-0.5=3.5$ and $4+0.5=4.5$, or through a range equal to $4.5-3.5=1$. Hence, reducing the incoming signal strength one-half, has reduced the beat strength one-half also, with corresponding decrease in the received signal. It is to be noted that the strength of **LOCAL** oscillations is very much **GREATER** than the incoming, as shown in Fig. 11, "A." and "B."

21. This law of **DIRECT PROPORTIONALITY** is one of the great advantages of C.W. and beat reception as compared to the case of simple detector action in which the above law does not hold. In simple detector action, the output of the detector is **PROPORTIONAL TO THE SQUARE** of the amplitude of the incoming oscillations.

RECEPTION THROUGH INTERFERENCE

22. Consider the case of periodically **REDUCED** amplitude of incoming signals. For the simple detector, if this amplitude were reduced 1/2, the output (ratio of audibility) would be reduced to 1/4 of its former value, whereas, for beat reception the audibility would be reduced to only 1/2.

23. In the case of periodically **INCREASED** amplitude of incoming signal, the method of beat reception still holds it superiority. Assume the increase to be due to an interfering signal or to static. If the peak amplitudes were increased by the ratio of 3 to 1, beat reception would give the interference an audibility ratio of only 3 to 1 whereas the simple detector would give it a ratio of 9 to 1.

24. In the reception of a damped wave, the note heard depends on the spark frequency, over which the receiving operator has no control. If the interfering signal has a pitch equal, or close to, that of the spark, it will be very difficult to receive the signal. In the beat reception of C.W., however, the operator has at hand an immediate means of changing the note of the desired signal. By merely changing the frequency of the local oscillations he may obtain a note of considerably higher or lower pitch than that of the interference.

CHAPTER IX

THE VACUUM TUBE AS A DETECTOR

1. **VACUUM TUBE USES IN GENERAL.** The present success of radio transmission and reception is based primarily on the proper functioning of the three element vacuum tube. There are many ways of connecting one or more vacuum tubes in transmitting and receiving circuits, but in all cases the operation of the circuit is due to the functioning of the vacuum tube or tubes used.

2. Vacuum tubes if their present tendency continues will replace all other forms of radio apparatus directly concerned in the reception or transmission of radio waves. In wireless communication they may be used as detectors, amplifiers, modulators or oscillators or as any combination of these. A description of these uses will be given in later chapters.

3. The operation of the vacuum tube is based upon **the thermionic emission of electrons** from the solid surface of the filament when heated.

4. In order that a current can flow in the vacuum tube and necessary attached external circuits, a voltage must be impressed between the **hot filament** and the **cold plate** and the plate must be made **positive** with respect to the filament.

5. In explaining these requirements in the operation of a vacuum tube, descriptions will be given; first, of the construction of vacuum tubes; second, the electron theory as applied to vacuum tubes; third, the operation of a two-element vacuum tube; and fourth, the operation of the three-element vacuum tube as a detector.

6. **DESCRIPTION OF VACUUM TUBES.** Essentially, a vacuum tube consists of an exhausted hermetically sealed glass tube which is cemented to a rigid base. The tube is exhausted by means of an air pump to such an extent that there is very little air or gas remaining within the tube. The tube contains three electrodes.

(a) **THE FILAMENT** of the tube is similar to the metal filament of an electric light bulb and except in smaller tubes, is constructed in one plane. The metal filament is made generally of platinum, fine tungsten, thoriated tungsten (which is tungsten treated with a fraction of 1% thorium to increase electron emission), or oxide coated platinum. The filament can be heated to incandescence by current from a battery or by other suitable means.

(b) **THE GRID** consists of a piece of fine wire, bent in a spiral or zigzag form, which ordinarily surrounds or encloses the metal filament.

(c) **THE PLATE** generally consists of a nickel (molybdenum or tungsten) open ended cylinder surrounding the grid or of two flat plates on either side of the grid.

7. The filament, grid and plate are insulated from each other, and leads from each terminate in lugs on the base of the tube. Figure 1 shows the construction of a 50-watt three-element vacuum tube (used as a transmitter) with part of the plate and base removed in order to show all connections in the tube to the lugs on its base. Figure 2 shows two views of a 5-watt receiving tube. View (a) is a side view of a typical three-element vacuum tube. In view (b) the glass bulb has been removed and the three elements separated to show in detail their construction and location relative to one another.

8. The two-element vacuum tube contains two electrodes, one a filament and the other a metal plate constructed similar to a three-element vacuum tube. Throughout this book, diagrammatic sketches of vacuum tubes will be indicated as follows: two-element as in Figure 3, and three-element as in Figure 4.

THE ELECTRON THEORY

9. **ELECTRICITY AND MATTER.** Chemistry teaches us that all matter is composed of molecules. These molecules are understood to be in constant motion, the temperature of the matter

depending upon the velocity of this motion. According to this theory, at absolute zero temperature the molecules would have no velocity.

10. A molecule is the smallest complete and normal unit of any substance which cannot be subdivided further without destroying its properties. Molecules are made up of smaller particles called "atoms," the latter are the smallest particles into which matter can be divided by chemical separation.

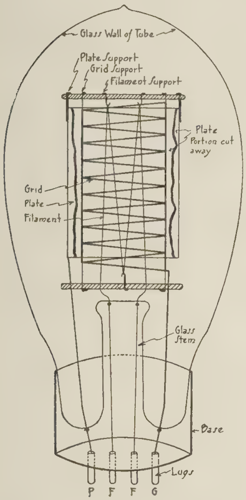
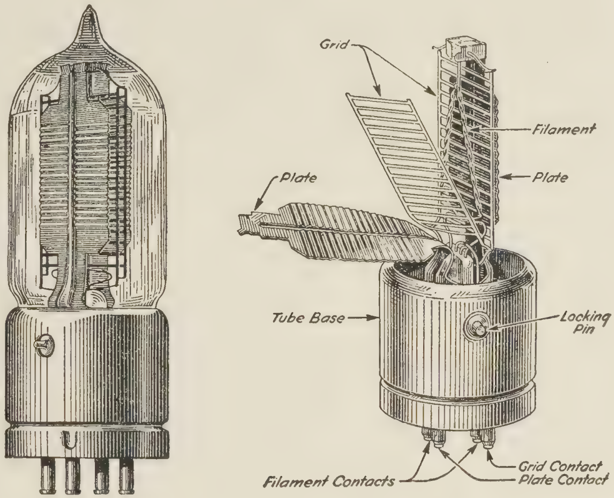


FIG. 1.—Typical Three Element Vacuum Tube used in Transmission Sets.



(a) Side View (b) Detail View

FIG. 2.—Typical Three Element Vacuum Tube Used in Receiving Sets.

11. According to the electron theory, an atom is not indivisible but is assumed to consist of a central nucleus, which is a positive charge of electricity, around which revolve, at a high speed in fixed orbits negative charges of electricity called "**electrons.**"

12. Electrons are contained in the atoms of all elements and each electron is a definite charge of negative electricity which is the same for all electrons. The electron is the smallest particle of any kind known to science.

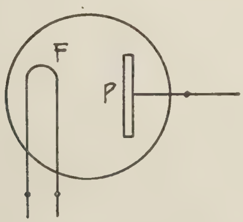


FIG. 3.—Diagrammatic Sketch Two element Vacuum Tube. *F* = Filament. *P* = Plate.

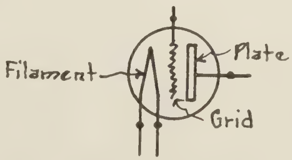


FIG. 4.—Diagrammatic Sketch of a Three Element Vacuum Tube.

13. Any uncharged body possesses no electrical properties since the positive nucleus of the atom is assumed to be neutralized by the negatively charged electrons. The structure of the atom is held together by the attraction exerted by the positive nucleus upon the negative electrons.

14. **FORCES BETWEEN CHARGED BODIES.** According to the commonly accepted modern theory of electrical phenomena there exist two kinds of electricity—positive and negative. A body that has associated with it less than the normal number of electrons is said to be positively charged, and one with an excess of electrons is described as negatively charged, the excess of one kind of electricity over the other being called the charge on the body.

15. Experiments prove that like charges repel one another and unlike charges attract one another.

16. **THE ELECTRIC FIELD.** The region between and surrounding a pair of charged stationary bodies is known as an **electrostatic** field or if moving an electric field. This field is generally represented by **electrostatic lines of force.** These electrostatic lines of force never terminate in vacant space but on charges, and opposite ends of a line of force terminate on charges of opposite sign.

17. **DIFFERENCE BETWEEN CONDUCTORS AND INSULATORS. ELECTRIC CURRENT.** The essential difference between solid electrical conductors and insulators is explained by the electron theory in the following paragraphs.

18. In the conductor the atoms are of such structure as to be capable of losing one or more electrons apiece (probably but one) with relative ease, or of passing an electron from one atom to another under the action of a very small difference of potential.

19. By maintaining a relatively small electromotive force between the terminals of the conductor a small electric intensity will be produced in the body of the conductor which will cause these "free" electrons to flow through the conductor from the negative terminal of the source of electromotive force) toward the positive terminal.

20. The free electrons are attracted toward the high potential end of the conductor (positively charged end) and repelled by the end of lower potential (negatively charged end).

21. This movement of the electrons constitutes the only current that flows in the conductor. To reconcile this statement with the usual convention that the direction of an electric current is from the positive (higher) to the negative (lower) potential the current is arbitrarily said to flow in the opposite direction to the electron flow. This is a correct assumption since electrons flowing in one direction will be the same as that of an equal current of positive electricity in the opposite direction. This difference in direction of current flow and electron flow should be understood thoroughly and constantly kept in mind, because in vacuum tubes the electron movement (such as from filament to plate) is the only current flow in the vacuum tubes in which we are interested.

22. In **insulators** or dielectrics—that is, materials of extremely low conductivity—the number of free electrons is extremely small, practically there are no free electrons. The structure of the atoms of these substances is such that the electrons are all "bound," the internal forces preventing the escape of any electrons from the atom except under the influence of an excessively intense electric field.

23. When an electromotive force is impressed across an insulator or dielectric (such as that of a condenser) the electrons in the atoms are strained in one direction, the atoms allowing a certain movement of the electrons with respect to their respective positive nucleus without permitting them to move from one atom to another. This momentary flow of electrons is known as a **displacement current.**

24. As soon as the electromotive force reaches a steady value the electron movement ceases. If the impressed electromotive force is increased or decreased, the electrons are either strained a little more or permitted to return a little to their normal position. **Thus a displacement current can flow only so long as the applied electromotive force is increasing or decreasing in intensity.** A constant applied electromotive force merely keeps the insulator or dielectric in a state of strain.

25. The restoring forces within the atom that tend to bring it back to its normal configuration are the cause of the equal and opposite displacement current that occurs when the condenser is discharged. If the voltage impressed on the condenser becomes excessive, the forces tending to tear the electrons from the atom become sufficiently great to disrupt the atoms along the electrically weakest path, and the result is a spark discharge through the dielectric. The freed electrons thus serve to conduct the current through the dielectric.

THERMIONIC CURRENTS

26. **THE EMISSION OF ELECTRONS BY HOT BODIES.** As explained above, a conductor contains a large number of free electrons which at ordinary temperatures are understood to be in orbital motion at relatively enormous velocities.

27. These electrons may be released in much the same manner as steam is produced from water. This escape of electrons is due to the velocity of the particles inside the metal or fluid increasing with increase of temperature until some of them attain a velocity high enough to break away and escape from the attraction of the surrounding molecules.

28. If in any piece of metal a difference of potential is applied between two points the electrons within the metal will acquire a slow drift in addition to their orbital motion. This slow drift of electrons constitutes an electric current.

29. To indicate the relative speed of this drift, in a copper wire, a velocity of drift of one centimeter per second will cause the wire to burn up. This contrasts with orbital velocities which may be many kilometers per second.

30. In metals the surface tension is very strong and their particles boil or evaporate only at high temperatures. In some few cases before the metal has reached a sufficient temperature to cause large numbers of the atoms to break through the surface tension of the metal, the electrons reach a state where they start evaporating out from the structure of their parent metal in appreciable quantities. As these electrons are liberated the parent atoms have a positive charge left on them which has a tendency to draw back the negatively charged electrons into the metal. The evaporation of electrons from a metal is conveniently carried out by making the metal in the form of a filament and enclosing it in a glass tube from which the air has been exhausted. The presence of oxygen in the tube tends to prevent the liberation of electrons and aids in the decomposition of the filament. In general the presence of any gas is undesirable, consequently, in the manufacture of vacuum tubes, many precautions are taken to reduce the residual gas to a minimum.

THE ELECTRON FLOW IN A VACUUM TUBE

31. **EDISON EFFECT. CURRENT FLOW IN TWO ELEMENT VACUUM TUBE.** About 1885 Thomas A. Edison discovered that a current could be made to flow through the partially evacuated space inside an ordinary carbon lamp if an unheated wire charged positively were inclosed in the space along with the heated filament. No current flow was obtainable when the filament was not heated. This property of a hot body in vacua permitting the flow of a current of electrons to the cold electrode was known as the "Edison Effect," and at that time found no practical application.

32. At that time this effect was thought to be due to the residual gas in the tube. More recently it has been discovered that this conduction of current is due to small particles of negative electricity (electrons) which are evaporated out of the filament at high temperatures.

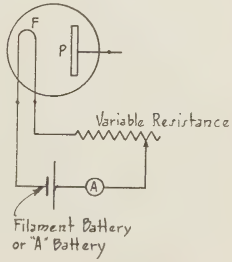


Fig. 5.—Filament Circuit Two element Vacuum Tube. F=Filament, P=Plate, A=Ammeter.

TWO-ELEMENT VACUUM TUBES

33. **THE FILAMENT. FILAMENT CIRCUIT.** The evaporation or radiation of electrons from an incandescent metal is conveniently and easily demonstrated by making the metal in the form of a filament and enclosing it in a glass tube from which the air has been exhausted. The ends of the filament should be connected as shown in Figure 5.

34. The function of the filament is to boil out or evaporate electrons much in the same manner as steam is formed from water. This function is easily accomplished since at ordinary temperatures the molecules of the conductor are: (a) in continuous motion, (b) their motion increases with increase of temperature, and (c) there are always free electrons present.

35. **SPACE CHARGE.** To demonstrate the function of the filament, suppose that the filament battery is of such a size that by varying the resistance of the filament rheostat, the electron (current) flow in the filament circuit is capable of heating the filament to any temperature. As the electron (current) flow is increased in the filament some of the electrons will form, at certain temperatures, a so-called "thick skin" on the surface of the filament. If the electron flow in the filament is increased a number of these electrons will break through this skin and leave the filament entirely. The electrons that leave the filament hover around the filament at certain distances forming what may be called "an electron cloud." Figure 6 shows a plan view of the electrons around the filament. The density of the electrons decreases rapidly with increase of distance from the filament. The "electron cloud" located between the filament and the plate causes the space in the immediate vicinity of the filament to acquire a negative **charge** commonly known as the "space charge."

Cross-section of Filament and Electron Cloud.

FIG. 6.—Distribution of Electrons around Hot Filament.

36. **SPACE CHARGE EFFECT.** This **negative space charge** tends to drive the electrons in the immediate neighborhood of the filament back into the filament, since like charges repel one another. This action is aided by the plus charge left on the filament when negative charges are removed from the filament in the radiation of electrons.

37. **THE PLATE CIRCUIT AND PLATE CURRENT.** Having explained the action of the electron emitting source (the filament) the next thing to explain is how these electrons can be made to carry charges through a vacuum and permit a current to flow in the external circuit between filament and plate. By connecting a plate battery with its positive terminal to the plate and its negative terminal to the filament, the plate will be made highly positive with respect to the negative terminal of the filament and so will attract some of these emitted electrons instead of letting them all return to the filament.

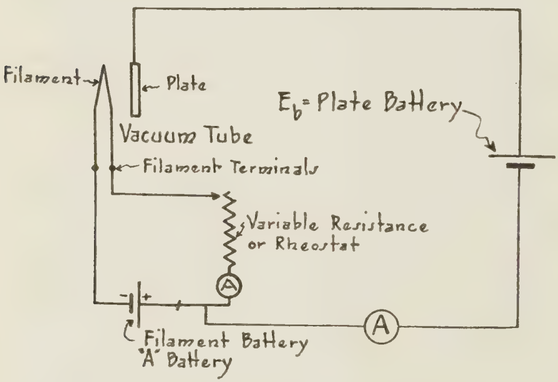


FIG. 7.—Typical Two element Vacuum Tube Circuit.

38. In as much as the plate is connected metallically to the filament through the plate battery, the electrons (attracted by the positive charge on the plate) after entering the plate will return to the filament through this circuit, thereby giving rise to a direct current. The circuit from filament through the vacuum tube to the plate and back **externally to the filament** provides a path for the flow of plate current. The portion of this circuit external to the tube is known as **"the plate circuit."** This passage of the electrons in the plate circuit is the only flow of current in that circuit, but in order to adhere to the usual convention the plate current is arbitrarily assumed to flow in an opposite direction to this electron flow.

39. The functions of the plate battery are: (a) to furnish the energy that is to be controlled by the vacuum tube, and (b) to create an electric field between the filament and plate of sufficient intensity to attract some or all of the electrons emitted by the filament. The higher the value of this plate voltage the greater will be the force of attraction of the plate for the electrons.

40. By maintaining the filament battery and the plate battery constant, a continuous flow of electrons (current) will pass through the plate circuit.

41. **CONDITIONS LIMITING PLATE CURRENT.** With a tube of given design the value of the plate current (I_p) depends on two conditions, one on the number electrons emitted by the

filament and the other the voltage of the plate battery. Commencing with a low plate voltage, if the plate voltage is increased, the plate current will increase until it meets with a space charge limitation or a temperature limitation.

42. **SPACE CHARGE LIMITATION.** Each emitted electron is acted upon by three forces:

(a) The repelling action of one electron on another due to their being like negative charges.

(b) The attracting force of the plate due to its positive charge.

(c) The attracting force of the filament due to the positive charge left on it when an electron is emitted.

43. As to whether an electron reaches the plate will depend entirely upon its location in the space between the filament and the plate and upon which of these forces predominate. With the lower voltages, the plate current is limited entirely by space charge. An increase in plate voltage partially neutralizes the space charge effect thereby resulting in an increase of plate current.

44. As the temperature of the filament is increased the number of electrons emitted from the filament will increase. These electrons can be considered as forming a cloud which is particularly dense just beyond the surface of the filament, just as steam particles congregate near the surface of water. The space charge effect due to the electrons in the space between the filament and plate may at last neutralize that due to the positive potential of the plate so that there is no force acting on the electrons near the filament to move them to the plate.

45. It must not be supposed that the space charge effect is caused by the same electrons all the time. After an electron has left the filament there are three forces acting upon it, first the force of attraction of the positively charged plate, second, a force of repulsion due to the electrons which have left the filament ahead of it and which on account of the repulsive action between similarly charged bodies are pushing it back into the filament, and third, the attraction of the filament itself. Whether the electron leaves the vicinity of the surface of the filament or not depends upon whether the force exerted by the plate or that due to the other two actions is the stronger. If the first predominates, the electrons will move over to the plate. If the repulsion and filament attraction are stronger they return to the filament, thus, unless the plate voltage is high enough to overcome the space charge effect due to the total electron emission of the filament, the plate current is limited by the space charge effect and not by the electron emission. **This is the normal operating condition.**

46. As each electron carries a negative charge they will repel one another. It can easily be seen that the more electrons emitted from the filament the more force that is being exerted by those electrons farthest away to prevent a further emission of electrons as each emitted electron tends to force the electron between itself and the filament back into the filament and the electrons between itself and the plate, toward the plate. At the same time the plate having a positive charge, tends to attract first those electrons nearest it.

47. Thus we see that electrons near the plate are constantly entering it, but new electrons emitted by the filament are entering the space, so that the total number between filament and plate remains constant as long as other conditions are constant.

48. After the temperature of the filament has reached a point where the effect of the electrons present in the space between filament and plate neutralizes the effect of plate voltage any further increase of the filament temperature is unable to cause further increase in current. The increased emission from the filament fails to increase the plate current on account of the space charge driving all of the increase in emission back into the filament. In consequence only a limited number of electrons can flow to the plate per second with a given plate voltage, and the remainder are compelled to return to the filament again.

49. **TEMPERATURE LIMITATION. SATURATION LIMIT.** With the higher plate voltages **all** of the electrons emitted by the filament are attracted to the plate as fast as they are emitted. Consequently, since the electron emission depends upon the temperature of the filament and nature of the material used in manufacture, the supply is necessarily limited, as the filament can only be heated to a certain point before it is destroyed. This value of the electron current (plate current) at which all available electrons given off by the filament are being absorbed by the plate (or by the plate and grid in the case of a three element vacuum tube) is known as the "saturation current."

Its value in the above case of high plate voltage depends entirely upon filament emission and is independent of the plate voltage. An increase in plate voltage does not increase the plate current but merely increases the velocity at which the electrons strike the plate, thereby resulting in increased heating of the plate.

50. Of late years manufacturers of vacuum tubes, in order to increase the electron emission at low temperatures and to reduce to a minimum the size of the filament battery, have resorted to the manufacture of filaments out of special metals such as thoriated tungsten, and platinum, coated with barium, calcium and strontium or other suitable oxides.

51. Tungsten is particularly suitable for vacuum tube filaments because it can be heated to incandescence and emits large quantities of electrons without rapid evaporation of tungsten. Similarly, filaments made of platinum-iridium and coated with barium and strontium oxides are suitable for use in vacuum tubes.

52. The normal operating temperature of an oxide coated and a tungsten filament is widely different. The tungsten filament in a vacuum tube operates at the same temperature as a tungsten filament in an electric light, while the oxide coated filament operates at a temperature varying from a dull red to an orange red.

53. Under normal conditions and with two filaments using an equal amount of power the emission from the oxide coated filament is considerably larger than from the tungsten filament.

54. Another type of filament which has only recently become commercial consists of a tungsten filament containing a fraction of one per cent of thorium. This filament operates at a temperature several hundred degrees lower than the pure tungsten filament. The emission occurs principally from the thorium. The small amount of thorium which is originally uniformly distributed throughout the filament, by diffusion gradually reaches the surface. At the surface the thorium is believed to form a layer held in place by adhesion of the tungsten and thorium molecules. Consequently, this layer is thought not to exceed one molecule in thickness. As this layer evaporates it is replaced by the addition of thorium diffused from the interior of the filament. When the supply of thorium is finally exhausted, the emission practically ceases without the filament having been burnt out. For equal power input to the filament, oxide coated and thorium filaments give about the same emission.

55. The characteristic curves of tubes with this type of filament are similar to those having bright filaments. These characteristic curves in many cases have a steeper slope due to closer spacing of the electrodes. Tubes that use the above special type of filament generally suffer from microphonic noises but are relatively free from trouble from crackling.

56. Care must be taken not to apply too great a plate voltage to a vacuum tube containing a thoriated tungsten filament because to do so causes electronic emission to be reduced to that value which the pure tungsten will emit. This reduction in electronic emission is due to the destruction of the thorium film upon which the action of the tube depends, and upon the gas evolved from the plate, at a rate greater than fresh thorium from the interior of the filament can diffuse to the surface. By coating the interior of the glass of the tube with magnesium, the destruction of the thorium film is retarded. When a vacuum tube has been treated with magnesium it presents a silvery appearance.

57. Any tube whose filament has been injured in this manner may be restored to normal by burning it for a time without any plate potential. This action causes a new thorium film to form without the risk of damage from gas. However, after a few such renewals, the thorium supply will be exhausted.

58. Tubes having thoriated tungsten filaments require a very high degree of vacuum, much higher than tubes with platinum filaments.

CHARACTERISTIC CURVES OF A TWO-ELEMENT VACUUM TUBE

59. The above limitations can best be studied by showing how they affect the shape of the characteristic curves of a vacuum tube. Let us consider what happens in a two-element vacuum tube having a good vacuum under the following conditions: first, when the plate voltage is held constant at a low value and then at a high value the filament current being varied, read and plotted

as abscissae against the corresponding values of plate current as ordinates, second, when the filament current is held constant at a low value and then at a higher value, the plate voltage being varied, read and plotted as abscissae against the corresponding values of the plate current as ordinates.

60. **EFFECT OF FILAMENT TEMPERATURE ON ELECTRON EMISSION.—CURVES SHOWING SPACE CHARGE EFFECTS.** Suppose that the plate voltage is kept constant at a low value E_p and that the filament temperature is gradually raised by increasing the current from the filament heating battery and at the same time readings are taken of the plate current and filament current and plotted then the lower characteristic curve in Figure 8 will be obtained. This curve shows that as the temperature of the filament is increased the number of electrons emitted from the filament increases.

61. The point where the curve starts to bend sharply to the right is where the space charge effect closely approaches the effect of the charge on the plate for that particular value of plate voltage. From this point increase in filament temperature although producing increased electron emission has very little effect in increasing the plate current, as shown by the remainder of the curve being straight and nearly parallel to the filament current axis. If now the plate voltage is increased to a new value E'_p, the plate current curve will rise higher before bending over as shown by the dotted portion of the curve in Fig. 8 because it takes a larger space charge to offset the effect of the plate at the higher voltage.

62. These curves also show that with higher values of plate voltage higher values of plate current may be utilized.

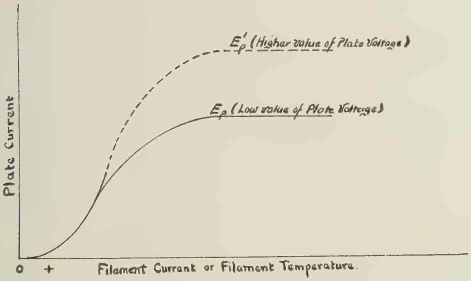


Fig. 8.—Static Characteristic Curves of a Two Element Vacuum Tube for Two Different Plate Voltages Showing "Space Charge Effect."

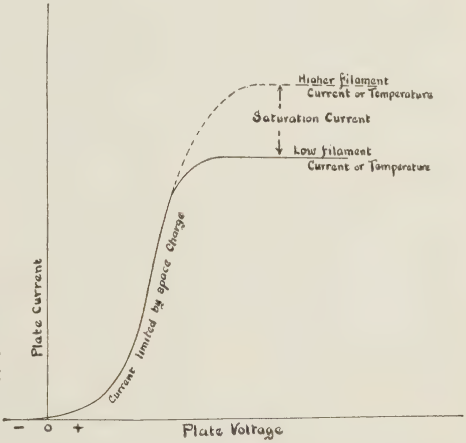


Fig. 9.—Static Characteristic Curves of a Two Element Vacuum Tube for Two Different Filament Currents Showing "Saturation."

63. **EFFECT OF PLATE VOLTAGE. VALUE OF SATURATION CURRENT.** Suppose that the filament current is kept constant at a low value, and that the plate voltage is gradually raised and at the same time readings are taken of the plate voltage and plate current and plotted then the lower characteristic curve Figure 9 will be obtained. This curve shows that with the plate voltage slightly negative some few electrons will reach the plate due to the initial velocity with which they are emitted from the filament. This curve also shows that the plate current increases with plate voltage. The value of the saturation current is indicated by the plate current curve bending sharply to the right and continuing very nearly horizontal.

64. At a higher filament temperature more electrons would be available so that the plate current would be able to increase to some higher value. The dotted portion of the curve of Figure 9 illustrates the condition when the temperature is increased and the plate voltage is varied and the corresponding plate current values are read and plotted. A study of these curves will show that the two curves coincide up to the saturation point of the curve plotted for the lower filament current and that the curve for the higher filament current continues to rise until it reaches its saturation point when it, in turn, bends over until nearly horizontal.

65. In studying the curves of Figures 8 and 9, care must be taken to establish the fact that although their shape is practically the same, they have an entirely different meaning. In Figure 8 the lower current portions indicate that saturation current is flowing and the upper part shows that plate current is limited by the space charge. In Figure 9 the upper flat parts of the curves indicate that the saturation current has been reached and the lower part shows that the space charge limits the value of the plate current.

66. **Unilateral Conductivity of a Vacuum Tube.** At this point in our discussion of the vacuum tube emphasis should be laid upon the fact that if in Figure 7, a two-element vacuum tube circuit, the filament circuit is open, no electrons will be emitted because the filament is cold. The space between filament and plate does not conduct current. Consequently, no current will flow in the plate circuit. Now, if the filament circuit is closed and electrons are emitted the space between the filament and plate will permit the passage of electrons toward the plate if it is positively charged. When the plate is negatively charged it repels the electrons and no electrons pass between the electrodes.

67. **Use of a Two-Element Vacuum Tube as a Rectifier.** If the direct current plate battery is replaced by a source of an alternating electromotive force, current will flow in the plate circuit only when the alternating electromotive force gives the plate a positive potential because the vacuum tube possesses unilateral conductivity. No current flows when the plate is negative. In other words, the alternating current is rectified into pulsating direct current.

68. **IONIZATION IN VACUUM TUBES.** The above description of the flow of the electrons in a two-element vacuum tube applies to one with a perfect vacuum. A "soft" tube is one in which the presence of a slight trace of gas appreciably affects the operation of the tube. A hard tube is one in which there is so little gas that the effect of the gas is negligible. In a rarefied gas with no voltage applied most of the electrons present are constituent parts of atoms but some few are free. These free electrons move about with great velocity and if one of them strikes an atom it may dislodge another electron from the atom.

69. Under the action of the electromotive force between plate and filament the newly freed electron will acquire velocity in the direction in which the colliding electron is moving and the positively charged remainder of the atom, called an "ion," will move in the opposite direction. This action of electrons colliding with atoms is called **"ionization by collision,"** and on account of the additional electrons, a relatively large plate current results. The positive ion moves off toward the filament and arriving there unites with sufficient electrons to form once more a neutral molecule.

70. The ionization provides more free electrons thereby making possible an increase in the plate current. At first it would seem an advantage to have ionization by collision, because a larger plate current can be obtained, but there are two difficulties which are so great that only hard tubes are now used to any extent.

71. The first of these difficulties is caused by the heavy positively charged ions striking against the negative filament, wearing away the filament. A second disadvantage is that too large a plate voltage may cause the partial vacuum to become appreciably conducting rendering the operation of the tube very erratic. This condition may be recognized by a visible "blue glow" in the evacuated space inside the tube (not on the surface of the glass). When the "blue glow" appears in a tube the plate voltage must be reduced instantly or else the tube is liable to burn out.

THE THREE-ELEMENT VACUUM TUBE

72. **FUNCTION OF THE GRID. EFFECT OF CHANGE IN GRID POTENTIAL ON PLATE CURRENT.** In a vacuum tube, for any given plate potential and filament temperature, if the space charge is neutralized, there will be an increase in the plate current; on the other hand, anything that will aid the space charge will result in a decrease in the plate current. In the three-element vacuum tube (see Figure 1) these effects are brought about by inserting a third electrode, called a grid, from its appearance, in the stream of electrons between the filament and the plate. The grid in performing these functions provides a means of controlling the current in the plate circuit through wide limits without changing the filament temperature or the plate voltage.

73. **"The grid circuit"** is the circuit external to the tube which connects the grid to the filament. The maximum effect of the grid can be produced by constructing the filament as a central unit for the liberation of electrons and practically enclosing it with the grid, which is in turn enclosed by the plate.

74. If the grid is charged negatively with respect to the filament, the charge on the grid will aid the space charge in driving the electrons back to the filament, resulting in a decrease in the plate current. In this case the number of electrons striking the grid will be very small, consequently, practically no current will flow in the grid circuit *FG C′ F* of Figure 10. Giving the grid a highly negative charge will repel all electrons with sufficient force to drive them back to the filament so that the plate current drops to zero.

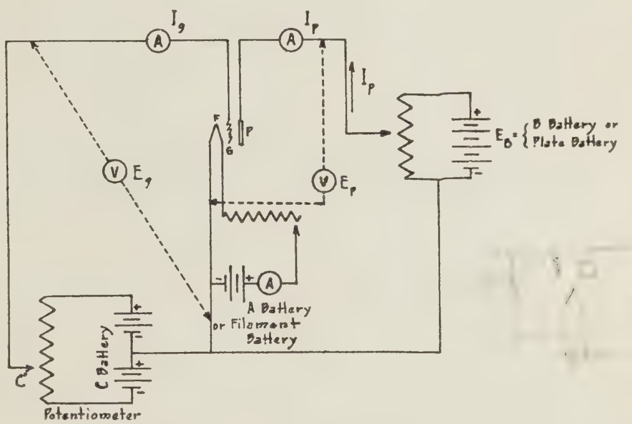


Fig. 10.—Three Element Vacuum Tube Connected for Determining Static Characteristic Curves.

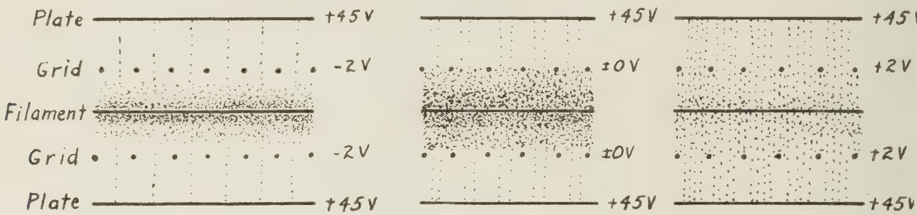
75. If the grid is charged positively with respect to the filament, the effect of the space charge will be neutralized to an extent depending upon the charge on the grid. In this case the electron current through the tube will increase until the field due to the grid charge is also neutralized by the space charge. Some few electrons will strike the grid and there will result a flow of current in the grid circuit. In general, the grid current will be small relative to the plate current until the grid voltage approaches the plate voltage. The above potentials on the grid may be obtained by inserting a grid battery in connection with a potentiometer in the grid circuit as shown in Figure 10. In this circuit if the pointer *C′* is moved towards the negative terminal of the grid battery, the potential of the grid will be negative and if in the opposite direction it will be positive and if in the center of the resistance wire of the potentiometer, the grid will be at zero potential with respect to the filament. **The negative terminal of the filament is the point of reference in a vacuum tube to which all voltages in the tube are referred.**

76. Since the filament emission is definitely limited under fixed conditions, any passage of electrons to the grid means just that many less electrons available to go to the plate. This passage of electrons to the grid constitutes the grid current in Figure 10 which flows in the circuit *FGC′F*. In the vacuum tube generator as commonly operated, at one point in the alternating current cycle the grid voltage closely approaches the plate voltage. At this time, the grid current becomes relatively large, and robs the plate of electrons which might otherwise reach it.

77. From the above discussion it is seen that the grid acts in the capacity of a second plate in so far as the electric field around the filament is concerned. The grid, however, is located be-

tween the filament and the plate and in consequence will have a greater relative effect on the limitation of the electron current by space charge than does the plate. In other words a small change in grid voltage will have a much greater effect upon the plate current than the same change of plate voltage. The addition of the grid thus changes a vacuum tube from a simple rectifier to amplifier, amplifying rectifier, oscillator and a modulator. This action of the vacuum tube will be discussed in later chapters. Figure 11 shows three views of the cross section of a three-element vacuum tube illustrating the electron flow from filament to plate when the plate voltage is forty-five volts and the grid voltage is, (a) two volts negative, (b) neutral and (c) two volts positive with respect to the negative filament terminals.

78. Figure 11 shows that the electron flow is governed by the algebraic combination of the effect of the charge on the grid, the space charge, and the charge on the plate. View (a) shows a few of the electrons passing through the grid to the plate; view (b) shows more electrons reaching the plate since the grid being neutral has no effect and their value thus depends entirely upon the space charge effect and the plate potential; and view (c) shows still more electrons reaching the plate since the charge on the grid is aiding that on the plate to overcome the space charge effect.



(a) Grid Negative. (b) Grid Neutral. (c) Grid Positive.

FIG. 11.—Effect of Grid Potential on Plate Current.

79. The importance of the grid control of plate current can be more readily appreciated when we stop to consider that the current and energy set in motion in the plate circuit may be considerable while the energy required to charge the grid to the desired potential is relatively small, due to the small capacitance between grid and filament.

80. **STATIC CHARACTERISTIC CURVES.** The operation of the three-element vacuum tube can best be studied by an examination of its static or direct current **characteristic curves.** These curves (Figure 12) can be obtained by connecting the tube as in Figure 10. The plate current-grid voltage and grid current-grid voltage curves are obtained by simultaneous readings of the values of plate current and grid current while the plate voltage and filament current are maintained constant.

81. In Figure 12 the solid line curves were taken with the plate voltage at 80 volts and the dotted curves with the plate voltage at 20 volts. Let us first consider the dotted line plate current-grid voltage curve. The curve starts to the left of the vertical zero axis where the grid voltage is -2 volts. This means that the grid is sufficiently negative to stop the flow of electrons to the plate so that the plate current is zero.

82. As the grid is made more positive the plate current curve rises rapidly and is practically a straight line until the plate starts to become saturated as indicated by the curve starting to bend to the right. With the grid voltage zero (grid and filament at the same potential), the plate current is about 0.2 milliamps. From this point the grid current starts to flow in the grid cicruit as indicated by the dotted grid current-grid voltage curve.

83. As the grid is made more and more positive, the grid current increases more and more and at the same time the plate current curve shows a slight decrease in current. When the grid voltage closely approaches the plate voltage the plate current curve suddenly starts to decrease and at the same time the grid current curve shows a rapid increase in current. This latter action is not shown in Fig. 12.

84. If the grid is continued to be made more positive the plate current will show a rapid decrease and the grid current a rapid increase, as the grid will take most of the emitted electrons. The plate current curve also shows that if the grid voltage is varied between ∓ 2 volts the plate current will vary between 0 and .8 milliamps.

85. In Fig. 12 the solid line curves show that when the plate voltage was raised the plate current curve moved bodily to the left keeping practically the same shape and having the same saturation point, and that the grid current curve moves down and slightly to the right; in other words, for any particular value of grid voltage the plate current is increased by increasing the plate voltage and the grid current is decreased. (This may not hold with low plate or highly positive grid voltage.)

86. While the characteristic curves used in the above discussion have been those from one tube, those obtained from any three element tube will be similar in shape. The values of the currents and

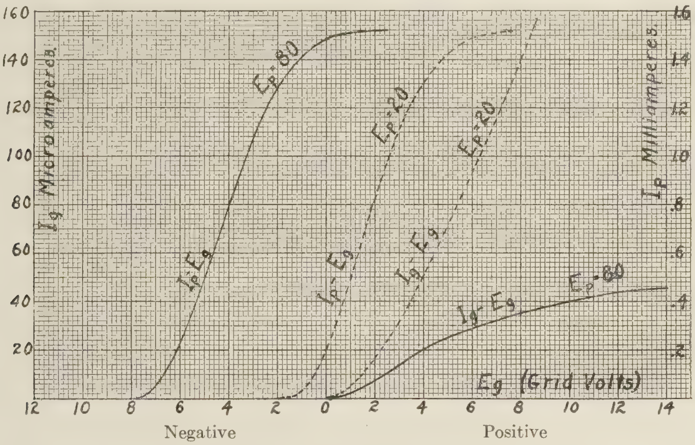


FIG. 12.—Static Characteristics of a Three Element Vacuum Tube.

also to a certain extent the shapes obtained depend upon the plate voltage, the filament temperature and the construction of the tube.

87. **OPERATING CHARACTERISTICS. EFFECT OF AN ALTERNATING VOLTAGE IMPRESSED BETWEEN GRID AND FILAMENT.** While the static characteristic curves determine what relations can possibly exist between voltages and currents, the values which do exist between them when the tube is operating in any of its applications is determined by the characteristics of the apparatus connected with the vacuum tube as well as by the characteristics of the tube itself. For example in Figure 14a, suppose, first, that an electromotive force ($e_g. = -.75 + .35 \sin \omega t$) is impressed between the filament and the grid of this three-element vacuum tube, second, that the static characteristic curves of this tube are the same as those in Figure 14a, and third, that there is a resistance load $R = 10{,}000$ ohms in the plate circuit. The only values of e_p and i_p that can coexist must satisfy both the equation $e_p = E_B - Ri_p$ and their values indicated on a static characteristic curve.

In the above e_p = instantaneous difference of potential between plate and filament, E_B = plate battery voltage, i_p = instantaneous current in plate circuit and R = total resistance in external plate circuit.

88. In a receiving set the successful operation of a three-element vacuum tube is due to the fact that the small radio frequency alternating current in the antenna causes a radio frequency alternating voltage to be impressed in the input or grid circuit between the filament and grid which in turn may be made to perform either one of the two functions; first, change the steady battery current into a pulsating current which may actuate the telephone receiver; second, cause a comparatively large variation in the plate current and therefore in the output circuit.

89. When a vacuum tube is performing the first of these functions, detector action is taking place and in the second case, amplifier action is taking place.

A vacuum tube connected as a detector will be described in this chapter and its operation as an amplifier will be described in Chapter X.

90. The curves of Figure 13 represent the condition when an alternating sinusoidal electromotive force ($e_g = -.75 + .35 \sin \omega t$) is impressed between the filament and the grid, with 10,000 ohms in series with the plate circuits.

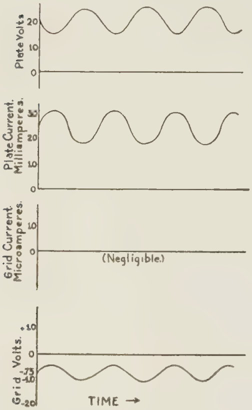


Fig. 13.—Wave Form of Grid Current, Plate Current and Plate Voltage When a Sine Wave Voltage is Impressed on the Grid.

In Figure 13, we see that the plate voltage has a low value when the plate current and grid voltage are high. A similar relation holds under all conditions of operation when the vacuum tube is used to produce an output.

RECEIVING CIRCUIT WITH VACUUM TUBE AS A DETECTOR

91. **DETECTOR ACTION.** A perusal of paragraphs 1 to 9 inclusive, Chapter VIII will refresh the mind as to the function of a detector, namely, to rectify the current flowing in the circuit in which it is placed, thereby permitting the current flowing in the telephone receiver to act cumulatively and thus produce sound. In other words, a detector is a device that has unilateral conductivity of the circuit, that is, permits current to flow through the device in one direction more readily than in the other direction. In a three-element vacuum tube, the principle of detector action is that whereby **like** changes in the voltage impressed on the grid produced **unlike** changes in the plate current.

92. Figure 15 shows a circuit utilizing the rectifying action in the plate circuit of a three-element tube. Here the terminals of the closed oscillating circuit that were formerly connected to the crystal detector and telephones are now connected between the grid and the filament of the detector tube.

93. In Fig. 15 the antenna circuit is tuned to resonance with the incoming signal by means of varying L_1 and C_1 then the secondary oscillating circuit L_2C_2 is tuned to the antenna circuit by varying L_2 and C_2. Generally only the capacities C_1 and C_2 are variable in receiving sets.

94. To understand the operation of a vacuum tube one must keep in mind at all times its characteristic curves. Referring to Fig. 15 suppose that signal oscillations in the secondary circuit induce an oscillatory e.m.f. (E_c) across the inductance L_2 and capacity C_2 which in turn is impressed across the grid and the filament.

95. In Fig. 14 are shown two views of typical characteristic curves. In part (*a*) and (*b*) plate detection is taking place

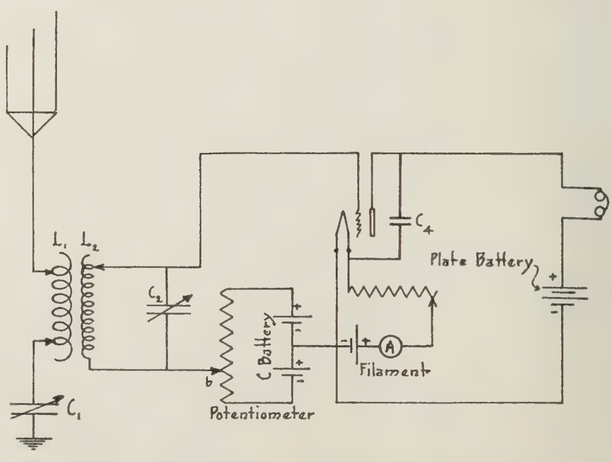


Fig. 15.—A Three Element Vacuum Tube Receiving Set, Using a Potentiometer in Grid Circuit, Connected for Plate Detection.

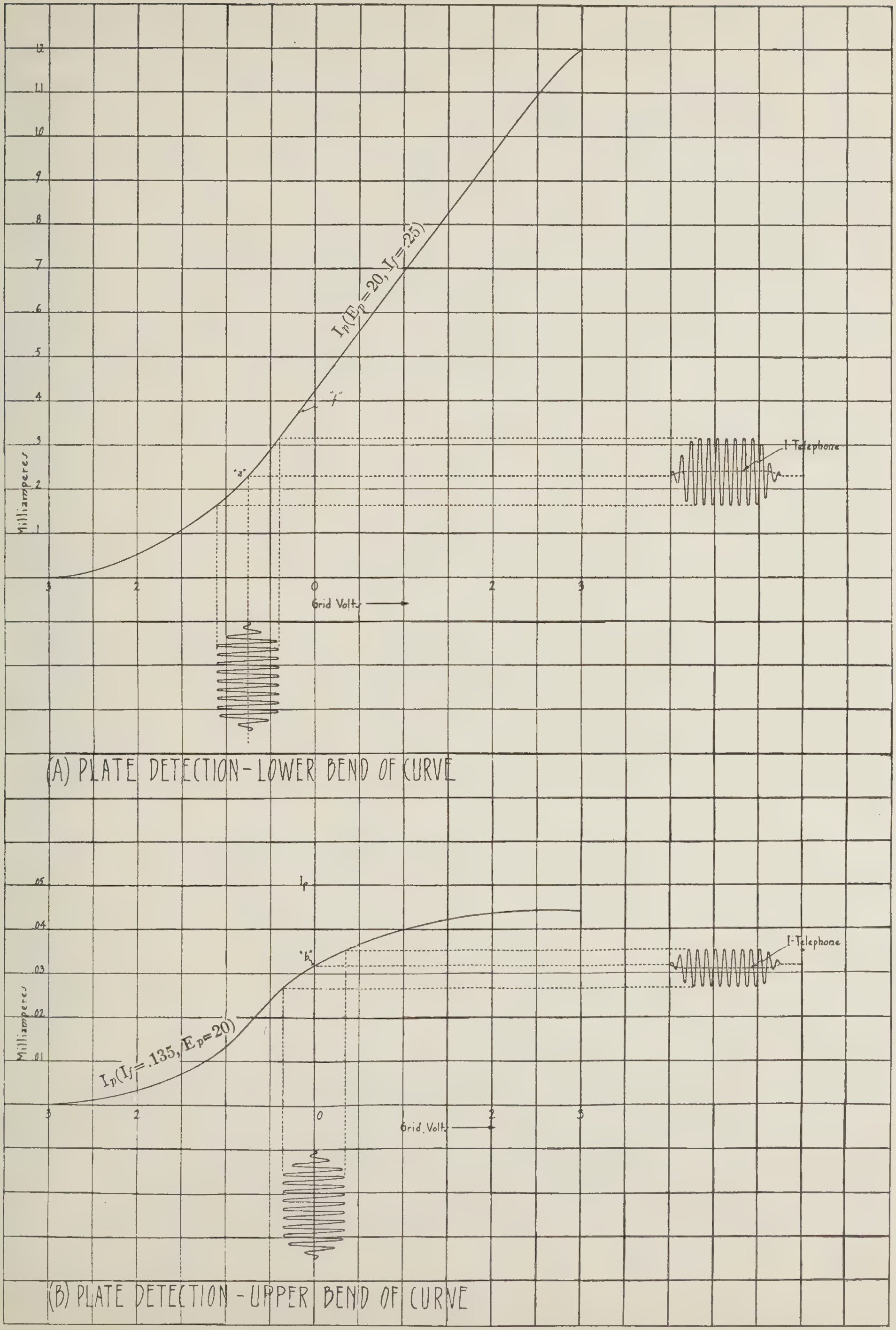


Fig. 14. Characteristic Curves of a Three Element Vacuum Tube Illustrating Plate Detection.

when the grid potential and filament current is adjusted so that the plate current has a value represented by the points "a" and "b" on the lower and upper bends of the plate current-grid voltage characteristic curve. Grid detection takes place most efficiently in the neighborhood of the point where the grid voltage-grid current curve bends most sharply as at "C." (See Fig. 21.). It is desirable to use such a plate voltage that a straight, steep portion of the plate current-grid voltage curves lies directly above "C." This produces maximum amplification of the signal rectified in the grid circuit. Only amplifier action (to be explained later) would take place when operating with a grid voltage corresponding to where vertical line through "f" intersects "X" axis. (See Fig. 14a.).

96. **Plate Detection.** Referring to Fig. 14 (*a*) the steady grid potential (often called normal grid potential) is equal to -0.75 volts. A vertical line through this point will be the axis for incoming signal voltage. On this grid-voltage line is drawn one undamped wave train representing the signal voltage applied to the grid circuit. From a study of the effect of equal but opposite changes in grid potential caused by these incoming oscillations it will be seen that increase in plate current for positive changes of potential applied to the grid is greater than the decrease of current for the negative half cycles, hence the average plate current and telephone current will be **increased** during each wave train.

97. These radio frequency fluctuations in plate current will not pass through the telephones, because the inductance of the telephones is too great to allow the current through them to change at radio frequency, but are "by passed," by the telephone condenser or through the capacity action of the telephone cords.

98. As the radio frequency voltage impressed on the grid is of constant amplitude, the plate current will remain unvarying at the **increased** value during each wave train.

99. Since the current which flows through the telephone is an averaged value of the current from the detector, the telephone diaphragm responds only to changes in this average value, and not at all to the radio frequency impulses of current. In order for a telephone diaphragm to produce audible sound, the diaphragm must be alternately attracted and released so that it can vibrate at a frequency between 20 and 20,000 vibrations per second. Consequently, when the average value of the plate current does not vary, any simple detector circuit, such as shown in Fig. 15, cannot be used to detect undamped waves. In order that the averaged value of detector current may vary at some audible rate, the amplitude of the received radio frequency wave must vary in the same manner. Since the amplitude of the radio frequency wave associated with spark and I.C.W. signals vary at an audible frequency or are divided in audio frequency groups these signals can be received with the hookup of Fig. 15.

100. In Chapter VIII, paragraphs 15-20 inclusive, is a description of the heterodyne and autodyne methods of reception which principle can be used in vacuum tube reception of continuous waves that are not divided into groups of audible frequency.

101. Greater variation in the voltage amplitude of the incoming wave shown in Fig. 14 (*a*) will control even greater changes in the plate current, operation then being effective over a larger range on the characteristic curve.

102. Summing up the above discussion, it is easily seen, first, that the fundamental principle of detector action is that equal but opposite changes in the value of the voltage impressed on the grid can be made to produce unequally large variations in the plate current; in other words, there is an apparent rectification of the plate current variations; second, the spark train frequency or the amplitude of the incoming oscillations **must vary at audible frequency** in order to be **heard.**

103. In Fig. 14 (*b*) is shown the various steps in the detection or rectification of an undamped wave train when operated at the upper bend of the plate current-grid voltage characteristic curve. This figure shows the form of (1) radio frequency oscillations impressed upon the grid, (2) radio frequency variations in plate current, (3) the audio-frequency fluctuations of telephone current.

104. A study of the figure will show that the negative alternation of the voltage due to the incoming signal effects a large decrease in the plate current while the positive alternation only effects a small increase.

105. As before, there will be fluctuations of the plate current keeping time with the arrival of wave trains, and there will be a sound in the telephone of a pitch corresponding to the number of wave trains per second.

106. **The Operating Point.** The name "operating point" is applied in this text to indicate what might otherwise be called a point of departure. It is a name for the point on any characteristic curve **about** which voltages and currents fluctuate during the normal operation of the tube. It is the point on any characteristic at which operation occurs when the current and voltage variations occurring are reduced to very small (infinitesimal) amplitude. With large amplitude variations which are confined to a straight portion of a characteristic the operating point is half way between the peak values of a symmetrical wave. If the operation of the tube occurs over a curved portion of a characteristic the operating point may not be half way between the limiting values reached. There is an operating point for each characteristic curve.

107. **Various Methods of controlling the Location of the Operating Point.** Just as in the study of the three-element vacuum tube apart from the construction of the tube itself, data for plotting characteristic curves is obtained by varying grid potential, filament temperature and plate potential, so the control of these same factors determines the location of the **Operating Point.**

108. When connecting up a tube for close adjustment of the operating point, it is current practice to make the plate potential of such a value that a slight variation of either the grid potential or filament temperature causes the operating point to attain the position desired.

109. The voltage of the grid may be regulated by means of a potentiometer but to avoid an extra control this is often omitted. In such a case a suitable value of plate potential and grid potential is chosen and the desired operating point is obtained by varying the filament temperature.

110. Before proceeding further in this discussion it is well to emphasize the fact that if the grid is connected to the (+) terminal of a battery it is at a positive potential and if connected to a negative terminal it is at zero potential **when referred to the standard reference point.** This standard point of reference in the vacuum tube circuit is the negative terminal of the tube filament. The potential of the grid is determined by the I Z drops and sources of e.m.f. between the grid and the standard reference point. For example, if the grid is connected directly to the negative terminal of the tube filament it is at "zero potential"; and since there is a drop of potential across the filament, the grid is then at a negative potential with respect to all other parts of the filament. In the same way, if the grid is connected directly to the plus side of the filament it is at a positive potential in relation to the negative terminal and to all parts of the filament except the plus end to which it is connected.

111. Figures 15, 16, 17, and 18 are typical circuits representing methods of adjusting the operating point of the tube. In these diagrams after the proper value of the plate battery has been chosen it is not changed, but it may be varied, if desired, by substituting another battery of a different potential.

112. In the circuit of Fig. 16, the grid is connected to the negative terminal of the tube filament through a variable resistance having a three volt IR drop. The drop across the filament terminals is assumed to be 4 volts and a seven volt battery is used to supply the filament current.

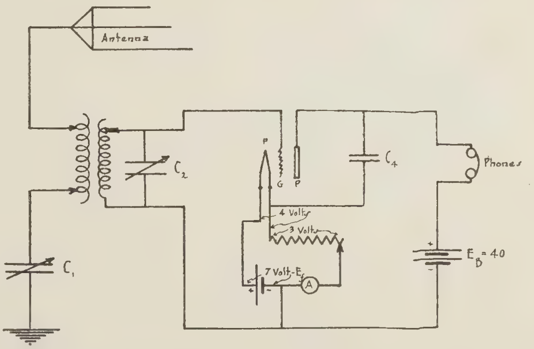


Fig. 16.—Receiving set using plate detection with adjustment of grid potential by variable resistance in filament circuit, grid connected to negative side of filament battery.

113. An inspection of the grid circuit shows that since there is a three volt drop between the filament battery and the negative terminal of the filament that the grid potential is three volts negative with respect to the negative end of the tube filament.

114. By using this value of the grid voltage, we determine the location of the "Operating Point." In order to obtain the "most efficient operating point" it may be necessary to vary the potential of the grid. This operation can be performed by varying the resistance in the filament circuit, but since these changes in resistance alter not only the normal potential of the grid in relation to the negative terminal of the filament, but also, the temperature of the filament, this is not a practical method. This particular hook-up provides grid potential from zero value to three volts negative.

115. In order to make the grid positive the grid connection should be connected to the plus terminal of the filament battery as in Fig. 17. In this figure, the grid is at the same potential as the positive end of the filament.

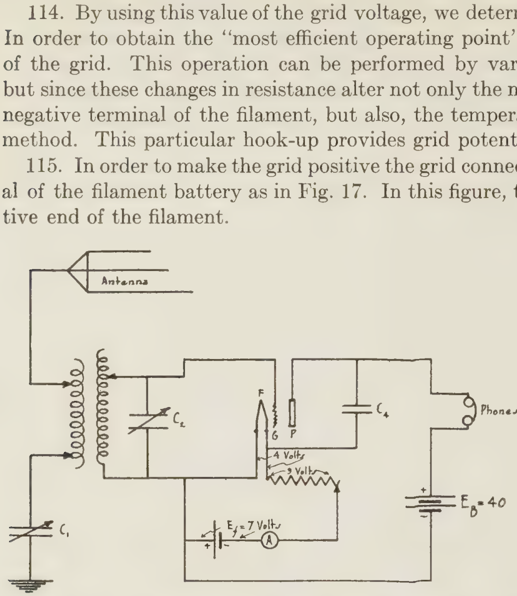


Fig. 17.—Receiving Circuit using Plate Detection with Adjustment of Grid Potential by Variable Resistance in Filament Circuit, Grid Connected to Positive Side of Filament.

116. With connections made as in Fig. 17 the working potential of the grid is plus four volts. While this positive bias could be changed by varying the filament rheostat only very small variations are permissible in this way as we must not depart appreciably from the rated filament voltage. If a greater range of adjustment of the operating point is desired the grid may be connected to a potentiometer as in Figures 15 or 18.

117. The effect of moving the slider "b" is the same as moving the normal grid potential to the right or left. With the values shown in the hook-up lof Fig. 18, the grid potential may be varied from four volts positive to three volts negative with respect to the negative end of the tube fiament. In all these circuits the normal filament temperature is obtained by adjusting the filament rheostat. The operating point is altered by varying this resistance in the filament circuit. Whenever the grid is made positive, the grid circuit becomes conductive, that is electrons flow from the filament to the grid or current from grid to filament. A study of the grid current-grid voltage characteristic curve taken with specially sensitive meters will show that the grid is slightly conductive even when it is negative.

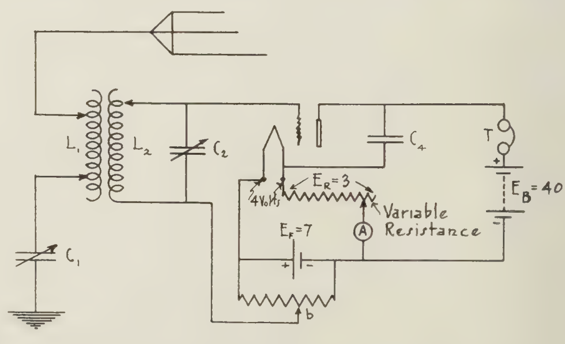


Fig. 18.—Receiving Circuit with Method of Adjusting Grid Potential by Potentiometer across Filament Battery from Plus Four Volts to Negative Three Volts.

118. If it is desired to regulate the potential of the grid at will, it may be connected up to a potentiometer as in Fig. 15. The "C" battery used in the grid circuit is frequently called a "biasing" battery. The potential of the grid is made plus (+) when the slider "b" is moved towards the plus end of the "C" battery and negative (−) when moved toward the negative end of the "C" battery and is neutral when midway between its terminals. The sole

purpose of the "C" battery is to move the vertical voltage line in Fig. 14, (*a*) and (*b*) to such a location that it will cut the characteristic curve near one of its bends, in other words, it controls the location of the vertical voltage line, which, after the "C" battery voltage is once adjusted properly, becomes the normal grid-potential line so far as the operating characteristics of the detector tube are concerned. Now that the method of obtaining the "operating point" is clear we will proceed with the second kind of detector action.

GRID DETECTION

119. **OPERATING POINTS.** In grid detector action the operating point on the $I_g - E_g$ characteristic should lie on the **sharply curved** part at the lower end, while the corresponding operating point on the $I_p - E_g$ characteristic, at the same time, should lie on the **steep straight** portion of that curve. (See Fig. 21).

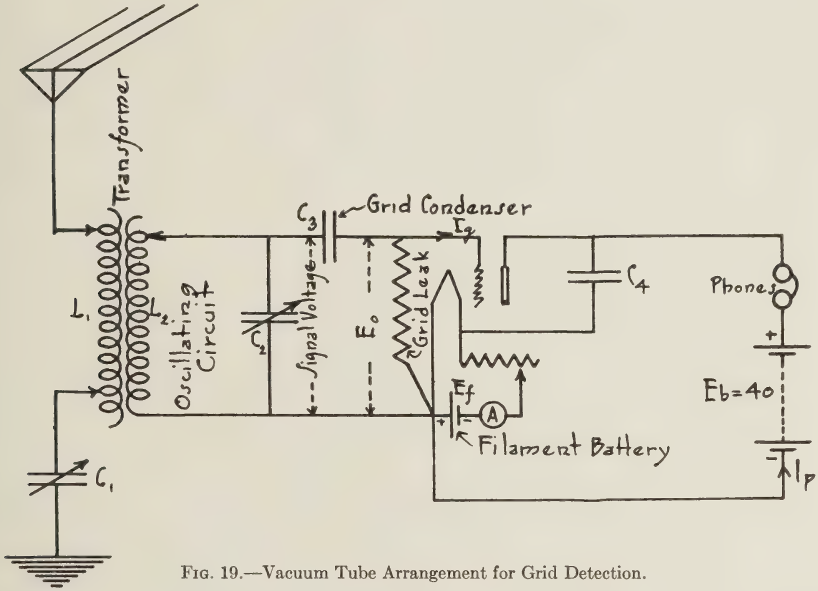


FIG. 19.—Vacuum Tube Arrangement for Grid Detection.

120. **CONTROL OF OPERATING POINTS.** The grid ($I_g - E_g$) current operating point requires that the grid be supplied with a steady current on the order of one microampere. This current will maintain the grid at a positive potential of a few tenths of a volt. The plate ($I_p - E_g$) current operating point requires only a suitable plate voltage.

121. **DETECTION OF I.C.W.** In order to obtain detection we **must have an a.f.** change in plate (telephone) current which is caused by the incoming **r.f.** signal. Consider the effect of adding one wave train of incoming r.f. voltage (No. 1, Fig. 21) to the grid under the above condition of operating points. The **average grid voltage** for the duration of this wave train will be the same as when no r.f. was applied. Remembering that we are operating on the straight part of the plate current ($I_p - E_g$) curve, we see that the incoming signal has had absolutely no effect on the **average plate current** and therefore we have no detection.

The **grid current,** however, (No. 2, Fig. 21) will increase more during the positive half of each cycle than it will decrease during the negative half of the cycle and therefore the **average value** of grid current is **increased.** If, now, we can employ this change of average grid current (which corresponds to the incoming wave train) to produce a corresponding change in grid voltage

(No. 3, Fig. 21) we will also produce a change in plate current (No. 4, Fig. 21) which will give us the desired grid detection **provided** the incoming wave trains are received at an a.f. and we can restore our grid to normal voltage between wave trains. The change of grid voltage is obtained by causing the unidirectional varying (average) grid current to pass through an impedance located between the grid and filament, so that the **iz** drop will effect the required change in grid potential. This change of potential will be in a decreasing (negative) direction so that at the end of the wave train (Point "*F*" Fig. 21) the grid may be considered to have accumulated a negative charge. Means must be provided for this charge to leak off, thus restoring the grid to normal voltage before the next wave train is received.

122. **THE GRID CONDENSER AND GRID LEAK.** In order not to waste the incoming (weak) signal voltage, the above mentioned impedance must pass this r.f. component **direct** to the grid with as little loss as possible—this is done by placing a small capacity, called the **grid condenser** (Figs. 19 and 20) directly in the grid circuit. In order to supply the small steady D.C. component required to maintain the grid potential at the desired operating point, the grid condenser is shunted by a high resistance called the **grid leak.** (Figs. 19 and 20). The capacity of the grid is on the order of .00025 μf and the resistance of the grid leak is from one to three megohms. The desired effect of this combination is to pass the r.f. but to offer high impedance to low frequencies.

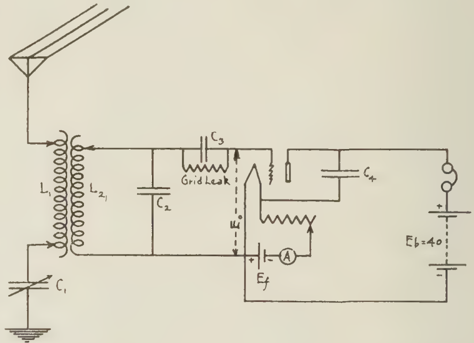


FIG. 20.—Vacuum Tube arranged for Grid Detection showing Alternate method of Connecting Grid Leak.

123. **RESTORATION OF NORMAL GRID POTENTIAL.** Referring again to point "*F*" (Fig. 21) it still remains to restore the grid to its normal voltage in order that we may be ready to receive the next incoming wave train. At the end of each wave train, due to the high impedance of the grid leak, this negative charge will have accumulated on the grid condenser. During the interval between wave trains four paths are available for this charge to leak off to the filament. They are (1) through the tube by being super-imposed on the "normal grid current," (2) through the grid leak, (3) through the imperfect insulation of the circuit, and (4) through the tube, carried by ionized gas. In a hard tube only the first two are of importance. As a result of this "leakage" the grid voltage and corresponding plate current become steady again at their normal value. This should happen before the next wave train comes along, and the circuit constants must be so arranged. When a tube has a very high vacuum a grid leak **must** be provided. A soft tube may work best without a grid leak.

124. **DETECTION OF MODULATED C.W. AND RADIO TELEPHONE.** In the above discussion we have considered the effects of an incoming signal of I.C.W. If now, the incoming cycles of r.f. voltage are caused to vary systematically, at an a.f. rate (modulated C.W.), the grid current will be found to contain three components which are of interest. There will still be the D.C. component, there will still be a r.f. component, and there will now be an a.f. component as well. This a.f. component results from the change of **average grid current** from one r.f. cycle to the next. The slowly varying charge accumulated in the grid condenser is **increased** by a component of grid current driven by the r.f. voltage and is **decreased** by the discharge of the condenser (see par. 125 below). We now have the required change of **grid voltage** which will be manifested by a corresponding a.f. change of **plate current** and will thus be heard in the telephones.

125. **TIME CONSTANT.** In order that the a.f. component of grid voltage may be practically the same as the a.f. variation (i.e. the modulation) of the r.f. voltage, the grid condenser discharge must be nearly complete in a time which is short compared to the length of one of the shortest a.f.

cycles with which it is necessary to deal. The discharge takes place through the grid-filament electron stream and through the grid leak in parallel. Representative figures for the resistance of these two might be 100,000 ohms for the electron stream and 2 megohms for the grid leak. The "time constant" of .00025 μf and 100,000 ohms is .000025 seconds, so that with the above values little distortion of a.f. should occur even with the frequencies as high as 10,000 per second. This discharge of the grid capacity superimposed upon the D.C. component of grid current from grid to filmaent, accounts for the fact, in radio telephony, that grid detection gives less distortion than would be expected if the condenser discharged through the grid leak only.

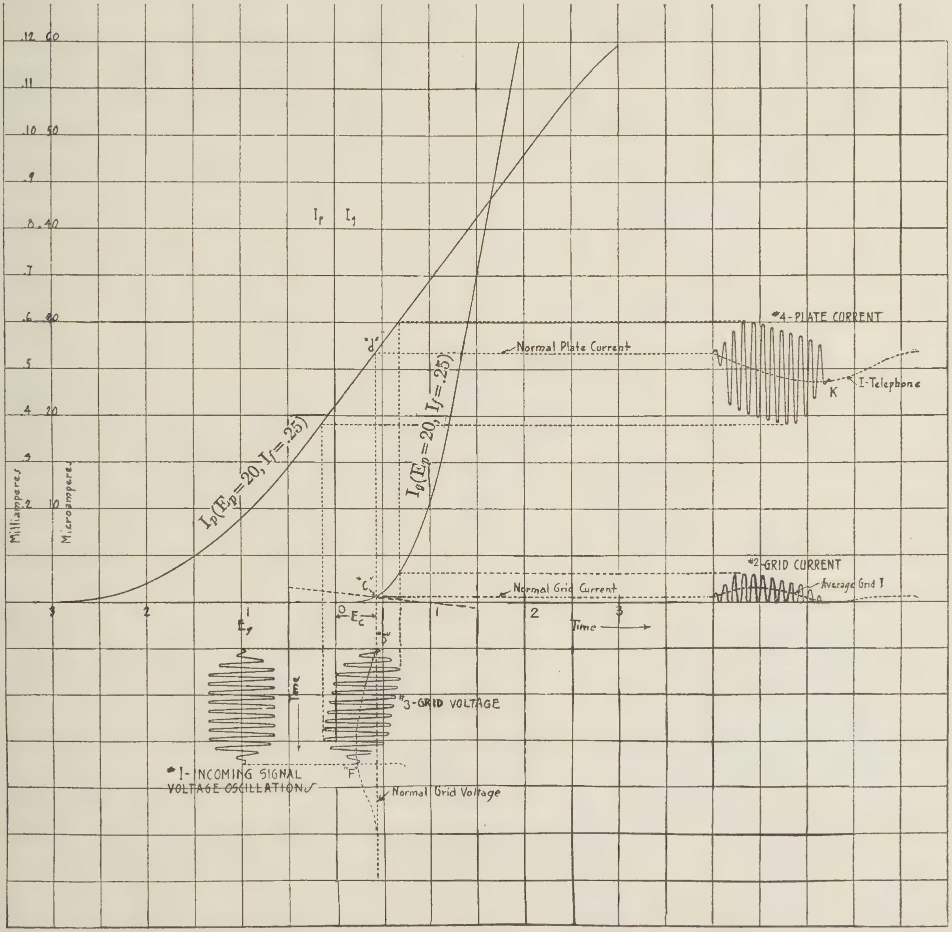


Fig. 21. Characteristic Curves of a Three Element Vacuum Tube Illustrating Grid Detection.

126. **AMPLIFICATION ACCOMPANYING DETECTION.** Detection has been accomplished when the a.f. component of grid current has been brought into existence. It is made useful in an amplified form in the plate circuit when the a.f. component of voltage is produced in the grid circuit. The change in plate current is of course larger than it would have been if the a.f. component of voltage had been applied directly to the plate circuit.

127. **POSITIVE GRID BIAS.** The most readily available source for the D.C. component of grid current is the battery which heats the filament. Assuming that the drop across the filament is one volt, there is nearly one microampere of D.C. produced in the grid circuit when a grid leak of 1 megohm is used—this is the "normal grid current" shown in Fig. 21. While the grid leak might be connected directly to the plus terminal of the filament battery (Fig. 19), it is common practice to connect it through the input coil system to the plus terminal (Fig. 20) of the filament.

CHAPTER X

THE VACUUM TUBE AS AN AMPLIFIER

1. The oscillating currents induced in radio receiving apparatus are sometimes so feeble that, when applied to a detector only, they cannot produce an audible response in the telephone. In order that we may get a readable signal, we must find some device for greatly increasing the strength of the incoming signals. Any device which produces a power output proportional to but greater than the power input, will serve this purpose. Such a device is known as an **Amplifier.** The amplifying device used in radio is the three element vacuum tube.

2. **AMPLIFICATION FACTOR.** Figure 1 shows three $I_p - E_g$ static characteristic curves. The amplification factor of a three-element vacuum tube is the ratio between small plate and grid potential variations which will produce equal variations of the plate current.

$$\text{Amplification factor} = \mu_0 = \frac{\Delta E_p}{\Delta E_g}.$$

In this formula ΔE_p is a small change in the plate voltage, and ΔE_g is the corresponding change in the grid voltage necessary to return the plate current to its initial value. These small changes in plate voltage and grid voltage are indicated in Figure 1. To further illustrate the value of the amplification factor suppose that originally $E_p = 60$, $I_p = 0.75$ milliampere and $E_g = 0$. Now if E_g is changed to $+1.5$, thereby increasing I_p, and it is found that E_p must be dropped to 45 volts in order to return I_p to 0.75 milliampere, then $\mu_0 = \dfrac{60-45}{1.5-0} = 10.$

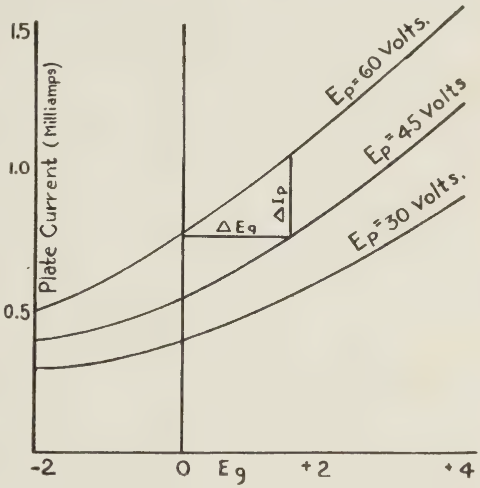


Fig. 1.—$(I_p - E_g)$ Static Characteristic Curves of a Three-Element Vacuum Tube.

3. This amplification factor depends primarily upon the geometrical proportions of the tube. Within the normal operating range, the value of this coefficient should change very slightly with conditions of operation such as E_p, E_g, and filament temperature. (See Art. 4022).

4. It must be remembered that the amplification is done by the **tube acting as a valve to control the output of the plate battery.** The tube itself does not supply any power (it only **controls** it) and an outside source of energy is necessary for use in conjunction with it. A crystal cannot act as an amplifier since its action consists of rectification only.

5. No matter how large the coefficient of amplification may be, it is obvious that the output of the amplifying tube cannot exceed the output of the plate battery. The real limit of amplification, however, is set by the characteristic curve of the tube. The part of the characteristic curve available for distortionless amplification is limited, first to the steep straight part of the curve, and second to that part corresponding to negative grid voltages. Distortion will result if these limits are not adhered to. The steeper the straight part of the $I_p - E_g$ curve, the higher the amplification will be. For ordinary detecting and amplifying tubes $\mu_0 = 6$ to 9, for special tubes $\mu_0 = 3$ to 40.

6. **INTERNAL PLATE RESISTANCE.** The internal plate resistance of a three-element vacuum tube is the ratio of the change in plate voltage to the change in plate current when the grid voltage is kept constant.

$$\text{Internal Plate Resistance} = \frac{\Delta E_p}{\Delta I_p} (E_g \text{ constant}) \cdot$$

7. **AMPLIFYING ACTION OF A VACUUM TUBE.** The general action of a vacuum tube as an amplifier is similar to its action when used as a detector. Its ability to amplify is due to the plate circuit power output available being considerably larger than the corresponding power input to the grid circuit when small voltages are impressed on the grid. Figure 2 is a circuit connected to illustrate the action of a vacuum tube as an amplifier. In Figure 2, there are two steady potentials, one E_b impressed on the plate and the other $E_c = -1.3$ volts connected between the negative filament and the grid to give the grid a negative bias with respect to the negative terminal of the filament so that the operating point will lie on the steep straight portion of the $I_p - E_g$ static characteristic curve as shown in Figure 1, and on the negative portion of $I_g - E_g$ characteristic (where I_g is substantially zero).

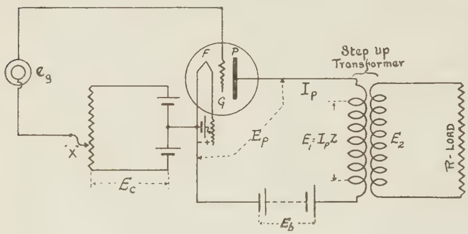


FIGURE 2— Circuit Connected to Illustrate the Action of a Vacuum Tube as an Amplifier

8. In Figure 2, the grid acting as an automatic valve or relay causes the amplitude of the small incoming oscillating voltage e_g between grid and filament to control a large proportional amplitude variation in the plate current which is in phase with the changes in the impressed grid voltage. The varying plate current may be considered to consist of two components, one a continuous current I_B and the other a superimposed alternating current i_p. The amplitude of the alternating component of the plate current will depend upon the steepness of $I_p - E_g$ characteristic curve, increasing with increasing slope of that curve (and of course varying with the alternating current voltage applied to grid).

9. In a vacuum tube as an amplifier, or in any case where the amplitude of the oscillations is small and the characteristic curves can be considered to be straight lines, the following important theorem holds for alternating currents encountered in the plate circuit: **The alternating current in the plate circuit of a three-element vacuum tube for a given voltage e_g impressed on the grid of the tube is the same in magnitude and phase as that which would flow in a simple series circuit consisting of an alternator of electromotive force μe_g (where μ = amplification factor of the tube), internal plate resistance R_0, and an impedance Z, where Z equals the external impedance in the plate circuit of the vacuum tube.**

10. This important theorem may be illustrated by taking into consideration that the alternating component of the plate current is produced by the combined effect of **an impressed alternating grid voltage E_g and a varying plate voltage E_p.** (See Figure 13, Chapter IX). Note that E_p is the alternating current component of the plate voltage. In this case the alternating plate current is, (vectorially)

$$I_p = g_m E_g + g_p E_p, \tag{1}$$

where g_p = The plate conductance of the tube, which is the reciprocal of R_0.

g_m = mutual conductance of the tube, and is equal to $\dfrac{\Delta I_p}{\Delta E_g}$, where ΔI_p is produced by ΔE_g when E_p is constant.

In paragraph 90, Chapter IX, it was shown that E_g and E_p were 180° out of phase, therefore, when the grid is going positive and thus increasing the plate current, the IZ drop will be increasing and thus reducing the plate electromotive force. This is indicated mathematically as follows:

$$E_p = -IZ \tag{2}$$

Substituting equation (2) in equation (1) we have:

$$I_p = g_m E_g - I_p g_p Z \quad \text{and solving for } I_p$$

$$I_p + I_p g_p Z = g_m E_g$$

$$I_p(1 + g_p Z) = g_m E_g$$

$$I_p = \frac{g_m E_g}{1+g_p Z} = \frac{\dfrac{g_m}{g_p}}{\dfrac{1}{g_p}+Z} = \frac{\mu E_g}{R_0+Z}$$

since $\dfrac{g_m}{g_p} = \mu$ and $\dfrac{1}{g_p} = R_0$, $R_0 + Z$ being a vector sum.

11. Referring to Figure 1, we see, that the continuous currents and voltages in the grid and plate circuits determine the part of the static characteristic curve where the tube is to operate and that they have no direct effect in determining the alternating currents and voltages.

12. The power represented by the alternating component of the plate current may be much larger than the power received by the grid owing to the fact that its source of supply is the plate battery, whereas the small amount of energy supplied to the grid circuit comes from the incoming signal (or in this case the alternator). The grid merely releases the energy stored in the plate battery, thus, the relaying action of a vacuum tube permits a very small amount of energy impressed on the grid circuit to release a large amount of amplified energy in the plate circuit. When this increased output is proportional to the input, the amplification is known as **distortionless amplification.**

13. One way of utilizing the large source of power represented by the alternating component of the plate current is to insert the primary of a transformer in the plate circuit as in Figure 2, in which case, only the alternating component would be present in the secondary.

14. It is to be noticed that the theorem of paragraph nine concerns itself with the AC components of currents, voltages, and power, to the entire exclusion of the DC components. It tells nothing about the DC components. Equivalent AC circuits may be drawn showing the application of this theorem to a vacuum tube. Fig. 3 is such an equivalent AC circuit including all of the details necessary for accurate computation of amplifier currents, voltages, and amplification.

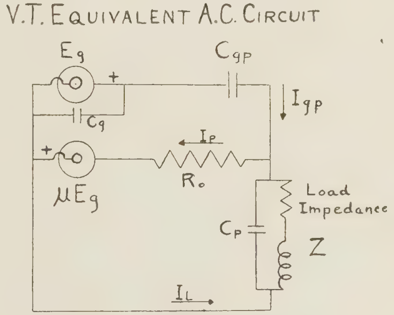


Fig. 3.

15. In fig. 3, E_g is the AC component of the voltage applied between grid and filament, μ is the amplification factor of the tube, R_o is the internal plate resistance of the tube and Z is the impedance of the load into which the tube feeds. C_p is considered as a part of the load circuit. It includes the parallel capacity of the load itself, the distributed capacity of the wiring, and the plate to filament capacity inside of the tube. C_{gp} is the direct capacity between grid and plate inside of the tube. C_g is the capacity associated with the grid circuit. It consists of the distributed capacity of the grid wiring plus the grid to filament capacity within the tube. From Kirchoff's Laws, the following vector equations may be written:

1. $E_g+\mu E_g=I_{gp}X_{cgp}+I_gR_0$
2. $E_g=I_gX_{cgp}-I_LZ_L$
3. $I_L+I_{gp}=I_p$

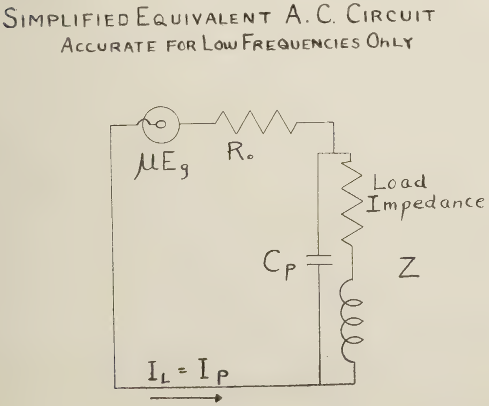


Fig. 4.

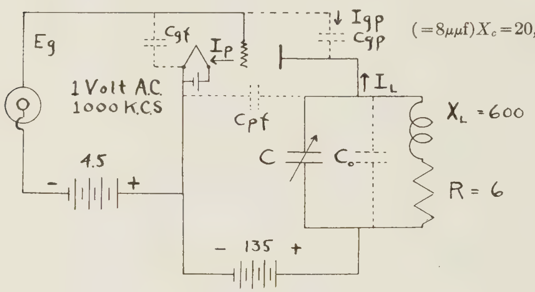
16. Fig. 4 shows a simplification of fig. 3, the same symbols being used so far as they are required. Fig. 4 is considered accurate

only for low frequencies. It may usually be used for a computation involving audio frequencies, but should not be depended upon for results involving radio frequencies.

17. Fig. 3 should be used if a computation involving radio frequencies is necessary. In such a case, C_g usually is dropped out of the circuit for the particular tube shown but is then added onto the plate circuit of the preceding tube if there is one.

18. To give a very rough idea of the relative importance of the current through C_{gp} it may be stated that computations show that with an ordinary receiving tube working at 1000 kcs. the current through C_{gp} is about the same size as that through R_o. As the current through R_o is the so-called main or plate current (born along by the electron flow through the tube) it is to be noticed that this says that at intermediate radio frequencies the capacity current may actually be as large as the AC component of the space current. It follows that at high radio frequencies the capacity current is apt to be much larger than the above component of space current. The current through C_{gp} is the one which produces the self oscillation of some amplifier circuits.

19. To give a more accurate idea of the results which may be obtained in a circuit with constants which are fairly representative, computations have been made and vector diagrams have been drawn for the circuit given in Fig. 5. While the DC plate voltage and grid bias voltage are shown here,



$(=8\mu\mu f)X_c=20{,}000$

Three values of tuning C used

Resonance at $C_{\text{LOAD}}=265\mu\mu f$

$C_{\text{LOAD}}=C+C_{pf}+C_0$

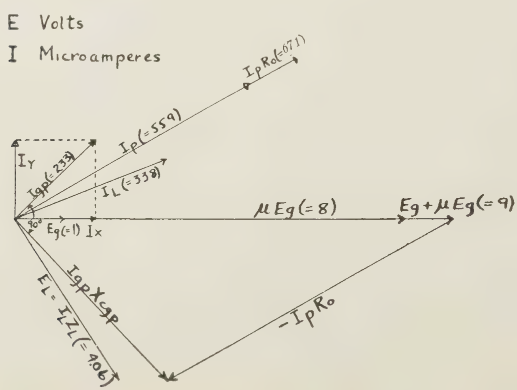
$R_0=12{,}000$

$\mu=8$

Fig. 5.—Actual Circuit—UX-201A

it will be noticed that they do not appear anywhere else. It should be borne in mind that the results obtained with the AC component of plate current could not be obtained if these DC supply voltages and the DC component of plate current were not present.

20. Since a radio frequency voltage is being considered in Fig. 5, the computations necessay for construction of the vector diagrams of Fig. 6 have been based upon the "equivalent AC circuit" shown in Fig. 3. Fig. 4 if used would give misleading results. This may be seen by noticing first



$C_{\text{LOAD}}=278\mu\mu f$
Load Impedance = 12,000 ohms
Load P. F. 20% (leading)
Load $E=I_LZ_L=4.06$
Grid Power Input $=I_xE_g=170\mu$ watts
Plate Power Output $=E_LI_L\times$P. F. $=276\mu$ watts
Apparent Grid Plate Capacity $=\dfrac{I_y}{2\pi fE_g}=25.5\mu\mu f$
Apparent Input Resistance $=\dfrac{E_g}{I_x}=R_a=5880.$
Power Amplification $=\dfrac{274}{170}=1.61$
Voltage Amplification $=\dfrac{E_L}{E_g}=4.06$

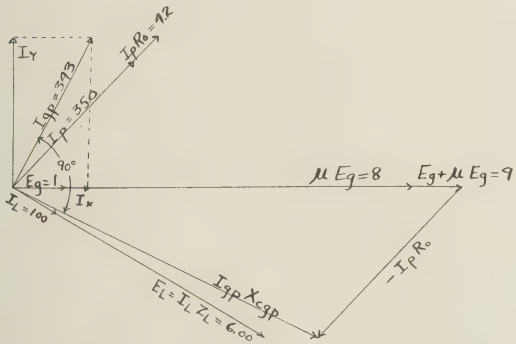
Fig. 6a.—Capacity Load.

that in Fig. 4 it is assumed that I_{gp} is so small as to be negligible and that therefore $I_L = I_p$ and second that the vectors in Fig. 6 show that these conditions are not satisfied even as a rough approximation.

21. The vector diagram of Fig. 6a is constructed from the following known data (see Fig. 5): $E_g = 1$ volt; $\mu = 8$; $Z_L = 12000$ ohms at a load power factor of 20% leading; $R_o = 12000$ ohms; $C_{gp} = 8$ $\mu\mu f$; and $f = 1000$ kcs. From the above data, $X_{cgp} = 20{,}000$ ohms, and $I_p = 559$ microamperes (computed vectorially) at the power factor angle shown. To the reference vector $(E_g + \mu E_g)$ is added the vector $-I_pR_0$ and from equation (1) par. 15, the sum of these equals $I_{gp}X_{cgp}$. I_{gp} leads its voltage drop $(I_{gp}\ X_{cgp})$ by 90°, and its magnitude is $I_{gp}\ X_{cgp}/X_{cgp}$, giving $I_{gp} = 233\mu a$ at the angle shown. From equation (3) $I_L = I_p - I_{gp}$, thus the vector $-I_{gp}$ is added to I_p giving $I_L = 338\mu a$ at the angle shown. I_L is at a power factor of 20% leading ($\cos\theta_L = .2$; $\theta_L = 78°28'$) and thus $E_L (= I_LZ_L = 338 \times 10^{-6} \times 12000 = 4.06$ volts) is set up lagging I_L by an angle of 78°28'. (Note that E_L might have been found by adding $-E_g$ to $I_{gp}X_{cgp}$ giving the same result; from this, I_L and I_{gp} could then have been found). Values of grid power input, plate power output, power amplification and voltage amplification can be found.

22. The three conditions represented by the three vector diagrams correspond to those which would be obtained by changing the tuning of the plate circuit by means of the condenser C. For 6a the resonant frequency of the load circuit is about 2.5% below that of the 1000 kcs applied to the grid. For 6b the plate circuit is resonant at 1000 kcs, and for 6c the resonant frequency of the plate circuit is about 2.5% higher than the 1000 kcs supplied to grid. The change of tuning results in a change in both the PF and the impedance of the load.

23. Comparing the results obtained here with the somewhat similar case of an alternator such as has been studied in AC work, the induced e.m.f. within the alternator is here replaced by μE_g. The internal impedance drop (within the alternator) is replaced by the resistance drop I_pR_o inside of



$C_{LOAD} = 265\mu\mu f$
Load Impedance = 60,000 ohms
Load P. F. = 100%
Load $E = I_L Z_L = 6.00$
Grid Power Input $= I_x E_g = 154\mu$ watts
Plate Power Output $= I_L E_L = 600\mu$ watts

Power Amplification $= \dfrac{600}{154} = 3.9$

Voltage Amplification $= \dfrac{E_L}{E_g} = 6.00$

Apparent Grid-Plate Capacity $= \dfrac{I_y}{2\pi f E_g} = 49\mu\mu f$

$R_a = 6500$ ohms.

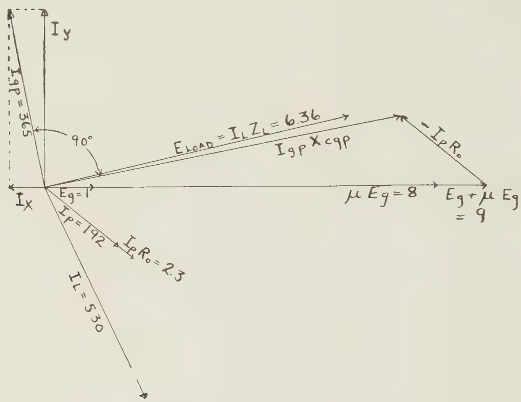
Fig. 6b.—Resonant (or Resistance) Load.

the tube. The terminal voltage is in each case the vector difference between the internal voltage and the internal drop. The "terminal voltage" for the tube circuit is marked E_L and, as in the case of the alternator, is also equal to the product of the load current multiplied by the load impedance.

24. The e.m.f. E_g and the capacity C_{gp} do not have any corresponding elements inside of an ordinary alternator. To determine their action they must be considered as being connected with reference to the load as shown in Fig. 3. It should be noticed here that there is a plus sign on one terminal of each of the two e.m.f. sources (E_g and μE_g) in this figure. This merely indicates the phase relation between the two e.m.f.'s by indicating that whenever the marked terminal of one is positive the marked terminal of the other is also positive (at the same time).

25. Aside from the general idea of these circuits, the main things to be observed are those in the labels beside the figures. In each case I_x and I_y are the in phase and quadrature components, respec-

tively, of the capacity current (I_{gp}) between grid and plate. Consequently, E_gI_x is the power put into the grid of the tube. This power is transferred to the plate circuit of the tube, (which is merely coupling and not amplification). The input of power to the grid circuit of the tube produces an effect which can be replaced by an "Apparent Resistance," symbol R_a, between grid and filament. This is a resistance of such value that, with the voltage E_g applied to it, the current which would flow would be equal to I_x and the power which would be consumed in it would be equal to E_gI_x. E_gI_y is the wattless voltampere input required to charge the grid-to-plate capacity. If the total voltampere input to the grid is required the charging current for C_g, Fig. 3, would have to be added vectorially to the two above.



$C_{LOAD} = 253\mu\mu f$
Load Impedance = 12,000 ohms
Load P. F. 20% (lagging)
Load $E = I_L Z_L = 6.36$
Grid Power Input $= I_x I_g = -72\mu$ watts
Plate Power Output $= I_L E_L \times$ P. F. $= 674\mu$ watts
Apparent Grid-Plate Capacity $= \dfrac{I_y}{2\pi f E_g} = 57\mu\mu f$

Amplifier Conditions Unstable
$R_a = 13{,}900$ ohms.

Fig. 6c.—Inductive Load.

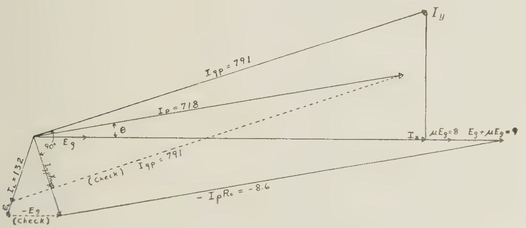
26. The voltage actually acting across the grid to plate capacity may by reference to Fig. 3 be seen to be the vector sum of the two e.m.f.'s minus the I_pR_o drop inside the tube, or, it is the terminal voltage of the device plus E_g. This voltage is greater than E_g whenever there is any load. This accounts for the real increase in I_y over what would be obtained if E_g alone acted on C_{gp} alone. It also accounts for the apparent increase in the capacity from grid to plate, since the e.m.f. actually acting is greater than that assumed to be acting. The change in apparent capacity with change of R_o (and consequently I_pR_o) is one of the reasons why the frequency generated by a VT generator varies slightly with filament current and plate voltage.

27. It is particularly important to notice the variation of I_x and E_gI_x with variation of the plate circuit impedance. With loads having a leading PF, E_gI_x is always positive since I_{gp} is less than 90° ahead of E_g. It has been incorrectly stated by some authors that a 100% PF load causes I_{gp} to lead E_g by exactly 90°. As a matter of fact I_{gp} does lead by exactly 90° only when I_pR_o is in phase with E_g. On account of the capacity current through C_{gp} this condition is not obtained when the load has 100% PF.

28. Fig. 6c furnishes an example of a particularly important case. In this case the load current lags enough and is large enough so that I_p also lags behind E_g in spite of the capacity current through C_{gp}. Whenever this occurs I_{gp} will lead E_g by more than 90°. As a necessary result of this, I_x has reversed in direction and the power "input" to the grid has become negative. (Negative input is of course the same as a real positive output, therefore we see that the tube is giving power output from both the plate and grid circuits at the same time.) If the power output of the grid circuit is large enough to supply the losses accompanying the current circulation necessary to maintain E_g, the circuit becomes a self excited generator. This frequently occurs in circuits which are intended to act as amplifiers only. When it does occur the circuit is no longer useful as an amplifier because the output has become independent of the separate excitation supplied for the grid.

29. To stop the trouble caused by self oscillation of an amplifier tube it would appear to be sufficient to put in resistance to use up the negative input. This is possible but not efficient in most cases. It is also possible to add some element to the circuit which will cause a current equal but opposite to I_x to flow to the grid. This is not common practice. One common type of circuit known as the neutrodyne provides extra circuit elements which pass a current to the grid which is approximately equal and opposite to I_{gp}. This approximate balance has only approximate phase opposition but the magnitude of the current can be adjusted until I_x is exactly cancelled.

30. To further emphasize the action of C_{gp}, Fig. 6d has been constructed for a case where its influence is even more pronounced than in the three preceding diagrams. This diagram is constructed for a case similar to 6b. The tube constants are the same, but changes have been made to permit the circuit to operate at 10,000 kcs. instead of at 1,000 kcs. This involves making both the coil and the condenser in the plate circuit smaller. The values taken in this case are 66.3 $\mu\mu f$ for C_L, 240 ohms for X_L, and 4.8 ohms for R. The grid input voltage is now 1 volt at 10,000 kcs. instead of 1 volt at 1,000 kcs. (Note now that X_{cgp} equals only 2,000 ohms.)



$C_{\text{LOAD}}=66.3\mu\mu$f.
Load Impedance = 12,000 ohms
Load P. F. = 100%
Load $E=I_LZ_L=1.58$
Grid Power Input $=I\times E_g=753\mu$ watts
Plate Power Output $=I_LE_L=218\mu$ watts
Power Amplification = 218/753 = .275
Voltage Amplification = 1.58/1 = 1.58

$$\text{Apparent Grid plate } C=\frac{I_y}{2\pi fE_g}=3.95\mu\mu\text{f.}$$

$I_p{}^2R_0 \qquad\qquad\qquad = 6190\ \mu$ watts
$\mu E_g\times I_p\times\cos\theta \qquad = 5655\ \mu$ watts
$\therefore$ Input power dissipated in $R_0 = 535\ \mu$ watts
Check $\underbrace{753}_{\text{Input}} - \underbrace{218}_{\text{Output}} \qquad = 535\ \mu$ watts

$$R_a=\frac{E_g}{I_x}=\frac{1}{753\times10^{-6}}=1328\text{ ohms}$$

FIG. 6d. Resonant Load. High Frequency.

31. Referring to Fig. 6d its proportions are immediately seen to be different from those of the preceding figures. I_{gp} has actually become greater than I_p. Consequently I_L, which is the vector difference of I_p and I_{gp}, is relatively small and is more than 90° from E_g. I_pR_o, the drop within the tube, is greater than μE_g, the voltage available within the tube. Looking at the figures presented beside the diagram it is seen that the circuit falls far short of producing amplification. The fact that the load voltage is slightly greater than applied grid voltage is misleading. It represents a voltage rise similar to that in a series resonant circuit and would disappear if any appreciable load were connected to the output. If, for example, the apparent input resistance of another stage just like this one were to be connected across Z_1 the resultant load impedance would be less than 1328 ohms (the apparent input resistance) instead of being equal to 12,000 ohms, and E_L would be much less than one volt. It is a fact, which may perhaps be seen from this, that accurate computation of a multistage amplifier requires starting with the output of the last stage and working back to the input.

32. In the equivalent A.C. circuit all of the power added to the circuit by a stage of amplification comes from the fictitious generator which supplies μE_g. Particular attention should be paid in Fig.6d to the fact that this power is less than the amount of power consumed within the tube in its internal plate resistance, R_o. This shows that instead of adding power to the circuit we are actually using up, within the tube, a large part of the power supplied to the grid circuit. The most important points in this high frequency case are thought to be the lack of amplification, the low apparent input resistance, and the consumption of input power within the tube. All of these detrimental effects are the result of the coupling produced by C_{gp}.

33. It should be seen from the preceding paragraphs that circuits which are intended for use as amplifiers should be so designed that they do not act as coupling units of the ordinary kind. If they do act as coupling units either the power input to the grid is made ineffective by passing it on to the

load circuit (and sometimes to the internal plate resistances of the tube), instead of using it to get voltage applied to the grid, or else there is a power feed back through the coupling which tends to cause the amplifier to oscillate. Apparently such feed back (which causes regeneration) should be desirable. Practically the difficulty of controlling it is such that only a small amount of it can be utilized.

34. In circuits of the Master Oscillator power amplifier type an additional disadvantage of capacity coupling through an amplifier is found. If such coupling exists, changes in the antenna system will affect the operation of the master oscillator.

35. The amplification that can be obtained from one tube is necessarily limited. In order to increase the amplification beyond that which one stage of simple amplification can produce resort must be made to the principle of regenerative amplification or else more than one tube must be connected in cascade. The principle of regeneration will be described in Chapter XI. When more than one tube is used, they are connected so that a varying voltage on the grid of the first tube produces in its plate circuit an undistorted plate current varying in phase with the impressed grid voltage. This varying plate current obtained from a large plate battery, when passed through a transformer or other suitable device causes a voltage to be impressed upon the grid of the second tube say from two to fifty times as great as that originally impressed on the grid of the first tube. In a similar manner, the output of the second vacuum tube can be made to supply an amplified voltage to the input of a third vacuum tube and so on. This process of increasing the amplification is known as multiple stage amplification.

36. The use of a large number of tubes as amplifiers is attended with difficulties due to regenerative effects which will be discussed in Chapter XI. Control of self oscillations in multiple stage amplification will be explained in Chapter XII.

37. **OPERATING POINT FOR AMPLIFICATION.** Since the effect desired is to increase the **strength** of the signal without **distortion,** we cannot use the tube at the same operating point as in a detector. This is obvious when we observe the curves of plate current oscillations in Figure 14a, Figure 14b, and Figure 21, Chapter IX, and see that there is considerable distortion due to the rectifying action of the tube. The operating point of the characteristic curve that must be used for amplification then, is one that will give the same proportional amplification for positive and negative changes of the incoming grid circuit oscillations. This condition is satisfied when the tube is operating on the **steep straight portion** of the characteristic curve as shown in Figure 7.

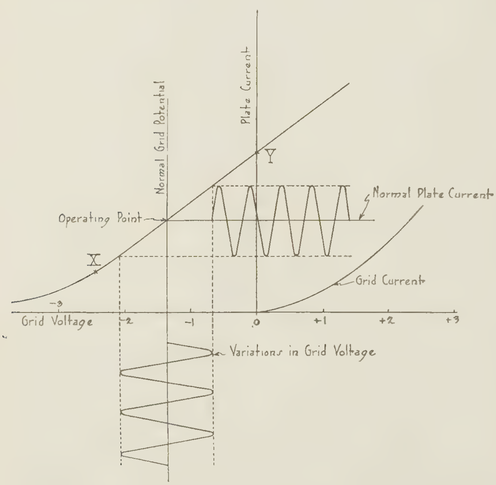


FIG. 7.—Action of Vacuum Tube as an Amplifier.

38. **SELECTION OF OPERATING POINT.** In selecting the best operating point for a tube, we must consult the characteristic curves, remembering that a change in the voltage of the plate battery will give a different curve in each case. The point must be such that the entire operation may be on the relatively steep straight part. If the curved portion of the characteristic curve is used at any time, there will be distortion of the signals.

39. Also, it must be remembered that if at any time the **grid** becomes **positive,** electrons will be attracted to it and grid current will flow as a consequence. This flow of grid current will oppose increase of grid potential which will affect the plate current. Hence we will get distortion in the amplification **unless the grid is always kept negative.** This limits the usable part of the straight portion of the curve to that lying between points X and Y in Fig. 7, since we get grid current if we go to the right of point Y, and distortion due to the curve of the plate characteristic if we go to the left of X.

40. **ADJUSTMENT OF OPERATING POINT.** With low plate voltage and small grid voltage the grid circuit may be connected to the **negative** side of the filament battery to give the proper potential to the grid. A potential divider across the filament battery as in Figure 18, Chapter IX, will give an adjustable potential and is better for that reason. With high plate voltage it may be necessary to connect an additional grid battery or "C" battery of small voltage in the circuit as shown in Figure 5 Chapter XII.

41. **DYNAMIC CHARACTERISTIC CURVE.** The characteristic curves used so far have been taken for the static, or "no load," condition of the tubes. It is important to understand that if there is any device to be operated connected into the plate circuit as in Figure 2, there will be some I_pZ drop through this, with the result that in general the voltage actually existing between plate and filament (E_p) is not equal to the supply voltage E_B. In other words, we might state that vectorially

$$e_p = E_B - i_pZ$$

Since the plate current I_p has an alternating component i_p in phase with the alternating grid voltage e_g then E_p must vary in cycles in a similar manner as shown in Figure 7.

42. In order to simplify explanation, suppose that we have in the plate circuit a resistance load. An increase in E_g in a positive direction causes an increase in I_p and a corresponding increase in the IZ drop in the plate circuit. In this particular case, the larger the plate current I_p, the smaller the plate voltage E_p, and vice versa.

43. In Fig. 8, the variation of plate current is shown for a certain assumed case in which the resistance of the load in the plate circuit is 10,000 ohms, and the supply voltage in the plate circuit is 500 volts. When the grid is sufficiently negative so that no plate current flows, there will be no loss of voltage in the plate circuit resistance and consequently the voltage actually delivered to the plate will be the full 500 volts. The point of the curve which this condition represents is shown at A.

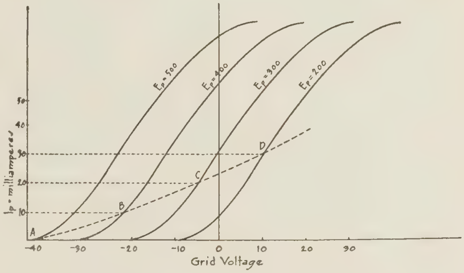


FIG. 8.—Dynamic Characteristic Curve of V.T.

44. If the grid voltage is now changed to a point where the plate current becomes say 10 milliamperes, the IZ drop in the plate circuit will be 100 volts and the voltage actually delivered to the plate will be $500-100=400$ volts. The point at which the tube is now operating is given by point B which is the intersection of the 400 volt E_p curve with the 10 milliampere line.

45. Now consider the case where the grid has been made sufficiently positive to bring the plate current up to 30 milliamperes. The voltage actually existing between plate and filament will have dropped to 200 and the tube will be operating at point D.

46. It is thus seen that instead of operating entirely on the curve for $E_p=500$ volts, the tube is operating on a different E_p curve for each change in grid voltage. If we draw a curve through points A, B, C, and D, as shown by the dotted line, this will represent the characteristic curve on which the tube actually operates under the conditions given above. This curve is known as a **Dynamic Charateristic Curve.** It might be called a "Load" characteristic as distinguished from the "No Load" condition where there is no useful load in the plate circuit. It should be noted that it is essential that the part of the curve that is used should be the **straight steep** portion as explained in paragraph 5.

47. The dynamic characteristic curve shown is obtained for a load consisting of non-inductive resistance only. If there is much **reactance** in the load the dynamic characteristic would take the form of a more or less flat loop or ellipse due to the difference in phase between the plate and grid potentials. Making the external impedance greater than the impedance of the tube will help to make the dynamic characteristic straight, but this will be done at the expense of the power amplification. The shape of the Dynamic Characteristic Curve is determined by the impedance in the plate circuit and upon the static characteristic of the tube (construction constants of the tube).

Referring to the equation $E_p = E_B - I_p Z$, we see, that the greater the value of Z, the larger will be the variation in E_p resulting from a change in plate current i_p caused by a certain change in grid potential e_g. Thus, the electromotive force across the impedance is an amplified reproduction of the grid voltage E_g.

48. **CLASSIFICATION OF AMPLIFICATION.** Amplification is classed as **Radio Frequency** or **Audio Frequency** depending on the frequency of voltages and currents being amplified. The principle is the same in each case but since there is a great difference in the frequencies to be handled by the two different classes, there must be a corresponding difference in design, and the parts are therefore not interchangeable. The use of radio frequency amplifiers avoids the amplification of low frequency disturbances and permits the detection of signals which otherwise could not be received. The use of audio frequency amplifiers increases the loudness of a detected signal. Audio frequency amplifiers are necessary in order to control sufficient power to operate loud speakers. As a rule, a combination of both types is used.

49. **TYPES OF AMPLIFIER CIRCUITS.** Amplifier circuits are divided into three types according to the kind of coupling used between the tubes:

(a) Transformer Coupled Amplifier Circuits.
(b) Resistance Coupled Amplifier Circuits.
(c) Inductance Coupled Amplifier Circuits.

50. The **TRANSFORMER COUPLED AMPLIFIER CIRCUIT** is illustrated in Fig. 9 which shows one tube used as a radio frequency amplifier, one as a detector, and one as an audio frequency amplifier; or, to use the customary nomenclature, it has one stage of radio and one stage of audio frequency amplification.

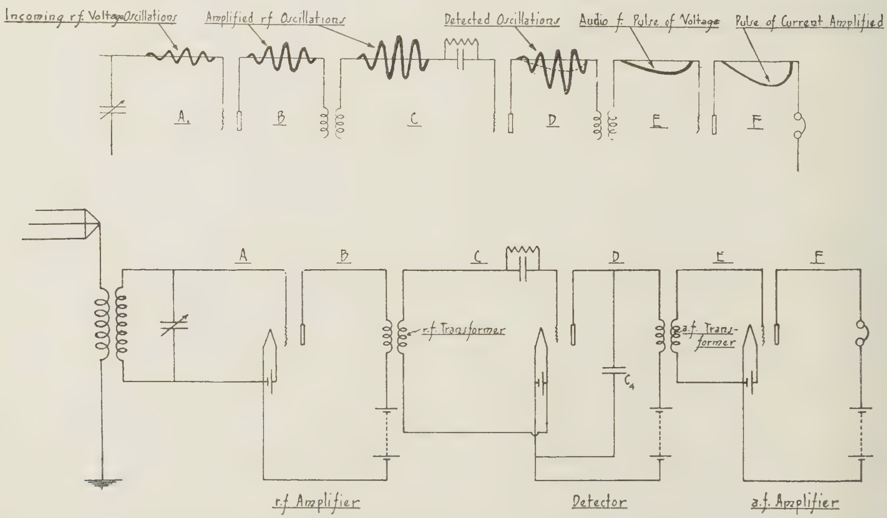


FIG. 9.—Transformer Coupled Amplifier Circuit Showing One Stage of r.f. and One Stage of a.f. Amplification. Upper Part of Figure Shows Oscillating Voltages and Currents in Different Circuits.

51. The incoming oscillations in the grid circuit A are **amplified** in the plate circuit B of the first tube. This circuit is coupled by a transformer to the grid circuit C of the second tube where the oscillations are **detected.** These detected oscillations appear in an amplified form in the plate circuit D. The primary of the transformer in circuit D is shunted by a small condenser which will by-pass the r.f. oscillations so that only the **average current** will flow through the primary of the transformer coils. This current through the primary of the audio-frequency transformer at any instant is deter-

mined approximately by taking an average of the plate current over a relatively small number of preceding radio frequency cycles. This current acting through the audio frequency transformer causes a similar voltage to be reproduced in the grid circuit E of the third tube. A corresponding amplified current will appear in the plate circuit F and since the pulses are at audio frequency a sound will be produced in the phones. No condenser will be necessary (or desirable) across the phones in this case since there are no radio frequency oscillations in this circuit.

52. Immediately above the diagram of connections is shown a skeleton diagram with the oscillating voltage in each circuit indicated. In D, the heavy line curve shows the plate current, while the dotted line indicates the resultant audio-frequency current through primary of the transformer. The radio-frequency component of the plate current returns to the filament through the condenser C_4.

53. Note that the grid circuit of the detector tube is connected to the **positive** side of the filament while that of the two amplifier tubes is connected to the **negative** side.

54. In order to illustrate the action better, each tube is shown with its own separate filament and plate batteries. In practice one common battery is used for all the filaments, and another one for all the plate circuits.

55. **Transformers** used for amplification coupling require particular design covering the conditions under which they are to operate. With audio-frequency amplification, the transformers usually have a step-up ratio ranging between 1 to 3 and 1 to 6. With radio-frequency however, they are usually 1 to 1 except for the lower radio frequencies. Both air core and iron core transformers are used for both r.f. and a.f. amplification, but the usual practice is to use an air core for radio, and an iron core for audio and the low radio frequencies.

56. The transformer type of coupling is considered superior in many ways to the other types and is the one most used in the Navy. The main objection to the use of transformer coupling is the fact that transformers will pass certain audio frequencies much better than other frequencies thus limiting their range of operation. This is due to the combination of the capacity effect between (a) turns of the primary, (b) turns of the secondary, and (c) primary to secondary, and the respective inductive effect of the primary and secondary windings. Due to the above capacity and inductance a resonant condition results. The range of frequencies to which an audio frequency transformer responds practically equally can be extended by making a more nearly ideal transformer. This will have more self-inductance and less distributed capacity and leakage reactance than the older designs of transformers.

57. Untuned (or very broadly tuned) high frequency transformers are built with a low ratio such as one to one. In this case, owing to the fact that the energy is transferred as much by capacity effect between windings as by the inductive action, additional turns of the secondary would fail to increase materially the ratio of transformation. Tuned high frequency transformers may use a higher turn ratio, such as four to one, since the capacity and inductive reactances are carefully arranged to neutralize each other.

58. **RESISTANCE COUPLED AMPLIFIER.** The resistance coupled amplifier circuit is shown in Fig. 10, there being two stages of radio frequency amplification and one detector shown.

59. The coupling resistances R_1 and R_2 are very high, usually from 50,000 to 100,000 ohms, inserted in the plate circuit. The value of R_1 and R_2 should be equal to or greater than the internal resistance of any of the vacuum tubes used. The total resistance of either D.C. plate circuit then includes one of these resistances, the internal resistance of the tube (from 5,000 to 25,000 ohms) and the resistance of the battery, etc., (which is so small as to be negligible in comparison with the others). Since R_1 and R_2 are much greater than the internal resistance of the tubes, most of the battery voltage (the IR drops) will be used up in forcing current through them.

60. Now if an incoming signal causes a change in the degree of positiveness of the potential of the grid, there will be a corresponding increase in plate current. A change in plate current means a change in the IR_1 drop, which is equivalent to saying that there will be a change in voltage across AB. Since the grid of the second tube is connected across AB through the condenser C_1 this change of potential is communicated to the grid of the second tube where it can be again amplified.

61. Condensers C_1 and C_2 are inserted to prevent the flow of direct current from the plate battery of the preceding tube to the grid of the succeeding tube. C_1 prevents the grid having the potential of the preceding plate battery impressed across it. The grid of the second tube would then be positive whereas the mean potential of the second tube should be about zero. While these condensers will not permit the flow of direct current, they will permit the flow of the alternating current. If condenser C_1 is short circuited the potential of the grid becomes highly positive, that is, equal to that of the preceding plate. The insertion of the grid leak D_1 permits the electrons that accumulate on the grid to leak back to the filament thereby restoring the grid to its initial potential and thus preventing distortion or the rendering of the tube inoperative.

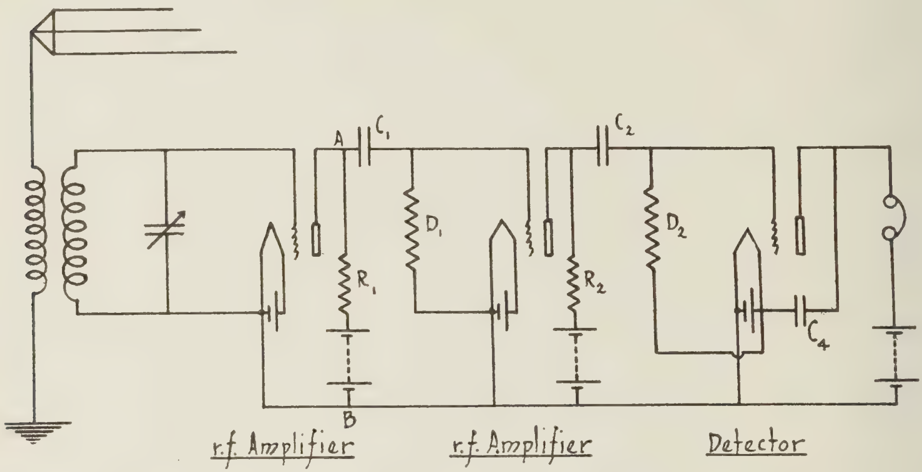


FIG. 10.—Resistance Coupled Amplifier Circuit Showing Two Stages of r.f. Amplification and Detector.

62. The principal advantage of the resistance coupled amplifier is that it gives substantially equal amplification over a wide range of frequencies without distortion. Compared to any other amplifier circuit, a higher voltage plate battery is required for proper operation. For the same amount of amplification, more tubes are required than for other types of circuits. It is sometimes used for radio frequency amplification and is coming into use for audio frequency (speech or music) amplification. The principal advantages of using resistance coupling are that its use permits substantially equal amplification over a wide range of frequencies and avoids the use of tuned intermediate circuits. Resistance coupled amplifiers are unsuitable for the higher radio frequencies owing to the tube capacity and the capacity effect between the leads to the resistance. (There is practically no inductive effect present to balance this capacity effect.) Resistance coupling is very seldom used for frequencies higher than 150 kilocycles.

63. The **REACTANCE COUPLED TYPE** of Amplifier Circuit as shown in Fig. 11 is similar to the resistance coupled one of Fig. 10, the principal difference being that a choke coil is substituted for the high resistance R_1 in the latter.

64. The action of the reactance coupled type is also similar to that of the resistance coupled one, the **reactance** of the coil being substituted for the **resistance** of R_1. The grid voltage of the first tube varies the plate current as before. The reactance of the choke coil, however, opposes these sudden changes of current and this IX drop across AB is transmitted to the grid of the second tube as before.

65. The Reactance Type has one advantage over the resistance type in that the choke coil offers little opposition to the flow of direct current. The amplification varies with the frequency more than in a resistance coupled amplifier, but not as much as in a transformer coupled amplifier.

THE SCREEN GRID TUBE

66. **DESIRABLE RESULTS.** Various results of the direct capacity between the grid and plate circuits of a three element tube have been pointed out in preceding paragraphs. Although most of the results of this capacity coupling are undesirable, in the few cases where these influences are not undesirable the desired result can be obtained by other means. It seems obvious from this that a circuit in which all direct capacity between the grid and plate portions could be eliminated would be highly desirable. Such direct capacity outside of the tube can be reduced to almost any desired minimum value by the application of suitable metal shields surrounding the parts of the circuit. However, it has been pointed out before that in the simple three element VT the direct capacity between grid and plate cannot be eliminated or even reduced to a low enough value to prevent troublesome effects.

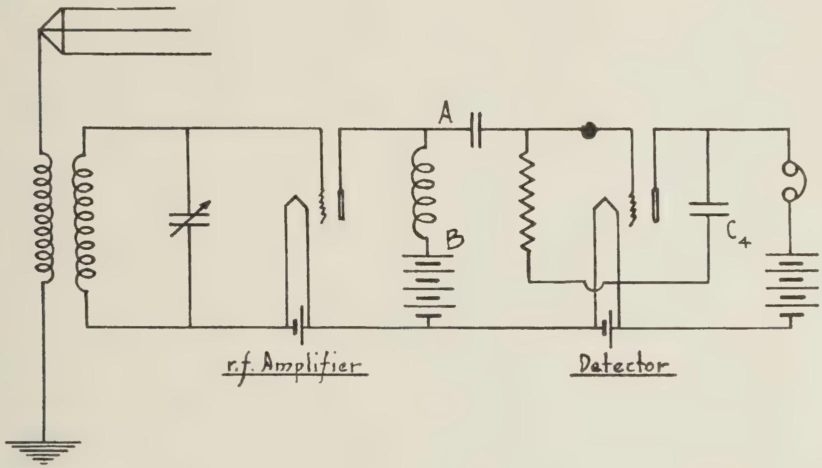


FIG. 11.—Reactance Coupled Amplifier Circuit Showing One Stage of r.f. Amplification and Detector.

67. **DOUBLE GRID TUBES.** The idea of a VT similar to the ordinary three element VT except for the addition of a second grid has long been known. Such tubes have been made in small quantities in this country and have been commercially available abroad at least since 1922. Their possible uses were numerous but usually involved using one of the grids for one purpose and the other one for some other purpose at the same time, much as the three element VT is used for two different purposes at the same time in reflex circuits. Each grid was performing a function which could be performed by the single grid in the simple tube.

68. **SCREENING WITHIN A TUBE.** A perfect, and at the same time perfectly useless method of eliminating the direct capacity between grid and plate within the tube would be provided by **completely** surrounding the plate by a metal shield connected to the filament. This absurd solution (?) for the problem is mentioned because it differs very slightly from a practical solution. It is found that the plate may be surrounded by a perforated screen, or better, a screen in the form of a specially shaped second grid and still have enough electrons get to the plate to make the tube useful. Such a screen could apparently be designed to eliminate any desired percentage of the direct capacity but a compromise must be made which will permit enough electrons to get to the plate to make the tube useful. It is perhaps a pleasant surprise to find that something in the order of 99% of the undesired capacity can be eliminated before the screen interferes too seriously with the electron flow. A tube using such a special grid as a screen may be known as a "screen grid" tube. The screen grid is seen to perform a function that could not be performed by the grid in a simple three element tube.

69. **CONTROL OF ELECTRON FLOW IN SCREEN GRID TUBE.** In the screen grid tube the electrons in the immediate neighborhood of the filament are screened from attraction by the plate to an even greater extent than the regular or "control" grid is screened from the plate. Consequently if the screen grid is connected to the negative terminal of the filament so that it does not attract the electrons, any reasonable value of plate voltage will give so little attraction for the electrons in the neighborhood of the filament and control grid that almost no plate current will flow. This is only what might have been expected as a result of putting in the screen grid surrounding the plate. Fortunately, it is not necessary that the screen grid be connected directly to the filament of the tube. It may be connected to the filament through a condenser whose capacity is large enough so that, at the frequency at which it is desired to operate the circuit, the capacity reactance is negligible. Then the screen grid may be charged positive (perhaps 25% as much as the plate). See Fig. 12. The screen grid will now attract the electrons hovering in the neighborhood of the

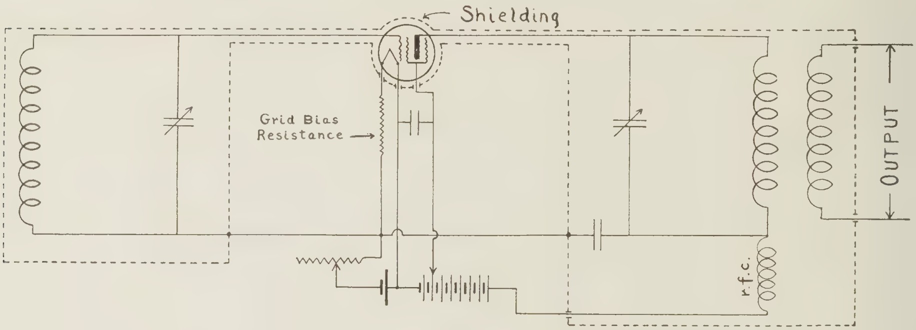


FIG. 12. Circuit for Screen Grid Tube.

filament and will get them started on their way toward the plate. Some of these electrons will go to the screen grid, but since the plate is more highly charged than the screen grid a considerable proportion of the electrons which reach the neighborhood of the screen grid will continue on to the plate. Considering only the operating range of the tube, within which the instantaneous value of the plate voltage is considerably higher than that of the screen grid, the operating condition is very different from the simple three element tube. This difference is due to the unique condition that the plate current depends only to a very slight extent upon the plate voltage. Put the other way around, this says that the plate current is nearly independent of the plate voltage in this range.

70. **CONSTANTS OF SCREEN GRID TUBES COMPARED TO STANDARD.** Since the internal plate resistance of a tube is defined as $\dfrac{\Delta E_p}{\Delta I_p}$ when E_g is constant, it is seen that the internal plate resistance of the tube will be much higher than normal because only very small changes in I_p accompany considerable changes in E_p. This is a distinct disadvantage of this type of tube construction. As a matter of experiment it is found that for a given change in grid voltage the plate current of the screen grid tube varies somewhere near as much as the plate current of a similar three element tube would change for the same change in grid voltage. This is accounted for by considering first that the number of electrons leaving the immediate neighborhood of the filament is controlled by the control grid in exactly the same manner in either tube, and second that some of this variation in electron flow from the filament goes to the screen grid and therefore is lost to the plate. This change in plate current per change in grid voltage is the mutual conductance of the tube. The above, restated, says that the mutual conductance of a screen grid tube can be expected to be smaller than, but at the same time not very different from, that which would be obtained with a similar three element tube. Smaller values of mutual conductance are not desired but the difference is not very serious. Since the plate current in the screen grid tube is easily changed

by grid voltage changes, but is only slightly affected by changes in plate voltage, the amplification factor tends to be very high, being approximately 300 in the UX-222 (screen grid) tube. This high value for amplification factor is a very decided advantage; in r.f. amplification it more than compensates for the undesirably high value of internal plate resistance.

71. **INTERNAL CAPACITIES OF SCREEN GRID TUBE.** Considering only the case where the screen grid is tied to the filament through a condenser of negligible reactance, the capacities found in this tube are the same in name as those found in the standard three element tube. The capacity from control grid to filament has added to it a second path through the screen grid, but the grid lead into the tube is kept away from the filament, so that the total value for capacity is about the same as in a standard three element tube. The grid to plate capacity as has been explained is greatly reduced, whereas in the standard tube it would be several micro-microfarads, it may now be only a few hundredths of one micro-microfarad. The capacity from plate to filament now consists almost entirely of a capacity directly to the screen grid, which is tied to the filament. Due to the proximity and extent of the screen, this capacity is considerably greater than in a standard tube. In the UX-222 it is about four times as large as in a corresponding three element V.T.

72. **USE OF SCREEN GRID TUBE AS A.F. AMPLIFIER.** Due to the combination of high internal impedance and relatively large plate to filament capacity the amplification tends to vary greatly with the frequency in the a.f. range. Consequently, the screen grid tube appears to be but poorly suited for use as an a.f. amplifier.

73. **EQUIVALENT CIRCUIT FOR SCREEN GRID TUBE.** Since only the magnitude of the constants involved in the input and output circuits of the screen grid tube differ from those in standard three element V.T. circuits, the same equivalent A.C. circuit applies with no changes whatever. It is of course possible to use a tube designed for screen grid operation in other manners. In general in such applications the equivalent A.C. circuit in its original form will **not** apply. In screen grid operation there is both an A.C. and a D.C. component of current going to the screen grid. The equivalent A.C. circuit tells nothing about **this** A.C. component, but as this component is not in the input circuit, and neither can it be utilized in the output circuit without interfering with the operation of the circuit, it is not necessary (nor even desirable) to include it in the equivalent circuit.

74. **USE OF SCREEN GRID TUBE AS R.F. AMPLIFIER.** The outstanding advantage of the screen grid tube for use as an amplifier at radio frequencies is its relative freedom from the internal grid plate capacity. To fully utilize this, great care must be taken to reduce the coupling, outside of the tube, between plate and grid circuits, to a very low minimum value. This requires very effective shielding. Sources of coupling, which with standard tubes would be entirely negligible, may cause serious trouble. Due to the very high internal resistance of these tubes, the amplifier output circuits which would be suitable for standard tubes do not provide anywhere near enough impedance to efficiently utilize the output of the screen grid tube. For this reason the constants of coupling transformers designed for these tubes must be quite different from what they would be for standard three element tubes. Fortunately, since the amplification factor of these tubes is so very high the utilization may be rather poor on a percentage basis, and yet give "good "amplification. For example, if a 201A (standard) tube succeeded in producing a voltage output equal to only 10% of the input times the amplification factor, (8), the output would be only 80% of the input and the device wouldn't be providing any amplification. On the other hand, if a circuit associated with a UX-222 tube produced an output voltage equal to 10% of the input times tha amplification factor, (300), the voltage amplification would be 30.

75. **USES AND ADVANTAGES.** It may be emphasized here that the reduced plate grid capacity to a large extent: (*a*) Avoids having a resistance component to the input impedance of an amplifier, (*b*) It avoids the passage of input energy direct to the output, (*c*) On high frequencies, it avoids the dissipation of the input energy in the internal resistance of the tube, (*d*) It practically eliminates the most serious source of the tendency to self-oscillation in amplifiers, (*e*) It makes r.f. amplification in receiving sets possible at much higher frequencies, (*f*) It provides a coupling tube for coupling

tube receiving systems which greatly reduces tendency for various oscillating receivers to interfere with each other, (*g*) It provides an oscillator whose tendency to change frequency with changes of such things as plate voltage and filament current is much less than for a standard tube, (*h*) It permits obtaining moderate amounts of r.f. amplification with fewer tubes than heretofore, and apparently permits obtaining amounts of r.f. amplification much beyond any need that is foreseen.

76. The screen grid tubes will be extensively used in all new V.T. transmitting sets purchased by the Navy.

CHAPTER XI

REGENERATION

1. **REGENERATION. The employment of the output amplified radio frequency current in the plate circuit of a three element vacuum tube to reinforce the input current to the grid of the same tube is called regeneration.** Regeneration is caused by the **feed back**, in proper phase, of the radio frequency current in the plate circuit from the plate circuit to the input or grid circuit through some form of resistance, inductive, or capacitive coupling.

2. **INDUCTIVE COUPLING.** One circuit with V.T. to produce regeneration is shown in Fig. 1. This circuit differs from other circuits studied in that the plate circuit contains an additional inductance L_3. The grid controls the variation of power delivered to the plate circuit by the plate battery "B". The resistance of the grid circuit determines the amplitude to which radio frequency oscillations in that circuit may build up. These oscillations are repeated in the plate circuit.

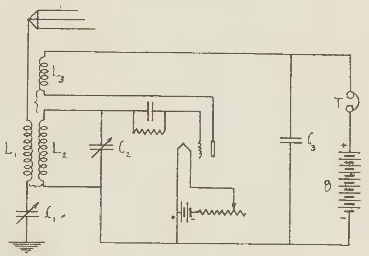


FIG. 1.—Regenerative Circuit with Inductive Coupling.

3. If the effective resistance of the grid circuit can be reduced the amplitude of the oscillations will be increased and the sensitiveness of the set will be increased, or for the same transmitted signal strength, reception will be satisfactory for a greater distance. To reduce the grid's effective resistance requires additional power **in the grid circuit.** This additional power is available in the plate battery but it must be transferred, in some effective manner, to the grid circuit.

4. By means of coil L_3, through inductive coupling, the variations of the plate current at radio frequency L_3 are made to induce an electromotive force in the grid circuit, thus assisting to overcome the grid circuit's effective resistance when the **variations** of **plate current** are in the **proper phase** relation with the electromotive force of the incoming signal. Thus energy from the plate battery of the plate circuit has been fed back to the grid circuit and this feature is called "regeneration."

5. By turning L_3 with respect to L_2, the proper coupling is secured. If the signal is weakened instead of strengthened the connections to L_3 should be reversed to secure the proper phase relation.

6. It would seem that the closer the coupling between L_3 and L_2 the greater the energy transfer from plate to grid circuit and that this could be increased until the effective resistance of the grid circuit is zero or negative. The latter results in a sustained oscillation which builds up to an amplitude limited by the limited filament emission and the increasing grid losses. In other words, with too close a coupling which supplies **more** energy than is required for mere regeneration, the tube becomes **self-oscillating.** That is, it sets up CW oscillations **within itself** which are independent of the incoming signal oscillations. But the natural frequency of the self-oscillations **is dependent** on the **capacity** and **inductance** of the oscillating circuit. This property of a V.T. will be studied in more detail under "The Vacuum Tube as a Generator of Continuous Waves."

7. Therefore, the best condition for "feed-back" or "regeneration" is the coupling just below that which would make the vacuum tube self-oscillating. The "howling" of a vacuum tube receiving set when being tuned is produced by too close a coupling between the plate and grid circuits causing the tube to oscillate.

8. The power for regeneration comes from the plate battery **only**; the variations of that power are controlled by the variations of the grid potential due to the incoming signal.

9. **CAPACITIVE COUPLING.** The filament, grid, and plate of a vacuum tube are conductors separated by a dielectric (the gas in the tube). Hence there is unavoidable capacity between these electrodes within the tube. The capacity from grid to plate always provides some capacity coupling between plate and grid circuits of a tube. This coupling is sometimes utilized in place of inductive coupling to produce regeneration or self-oscillation.

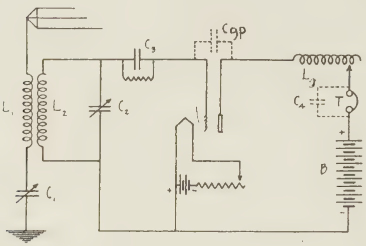


Fig. 2.—Regenerative Circuit with Capacitive Coupling.

10. A regenerative circuit illustrating this principle is shown in Fig. 2. The capacity, as indicated by the upper condenser in dotted lines, is in the tube between the grid and the plate. It is through this capacity that the coupling exists between the plate and grid circuits. Sometimes a condenser is actually used and connected outside the tube as shown by the dotted lines.

11. This circuit operates on the principle of the transfer of radio frequency energy from plate to grid through the capacity existing between these two. In order that this change of voltage on the plate may be of the proper phase relation the impedance of the plate circuit must have inductive characteristics for the flow of radio frequency currents, and must also provide a ready path for the audio frequency and direct current components. To secure this condition, a parallel inductance and capacity or its equivalent, an inductance coil with distributed capacity, for instance L_3, is very effective when adjusted properly. Such a coil should be designed to operate at a point **near** its radio frequency resonant condition. By varying the number of turns of L_3 suitable regeneration may be obtained at any frequency, within the limits of the set.

12. **"TUNED PLATE" CIRCUIT FOR REGENERATION. CAPACITIVE COUPLING.** This type of circuit is shown in Figure 3. It is similar to the circuit of Figure 2, but distinct differences also will be noted. There is no condenser across L_2, the distributed capacity between turns of the coil being sufficient. The grid circuit is tuned to the incoming frequency by turning the variometer L_3 thus changing its inductance. The only inductance in the plate circuit is the variometer L_4, the impedance of the radio frequency plate circuit L_4C_4 being controlled by turning L_4. The two variometers are not inductively coupled in any way, the coupling between plate and grid circuits being through the inherent capacity of the tube itself. (See Fig. 6c, Chap. X).

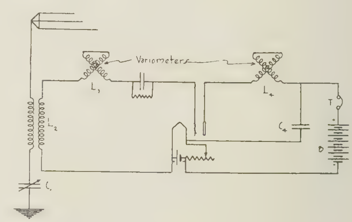


Fig. 3.—"Tuned" Plate Regenerative Circuit.

13. By means of the large inductance the electromotive force oscillations are made large. By turning the variometer L_4 the impedance of the plate circuit is made inductive, this being the proper condition for feedback. Thus the plate circuit is "tuned" to control the regeneration, this hookup is called the "tuned plate regenerative circuit" (Note that the plate circuit is **not** resonant at the received frequency, that is, the plate circuit is "tuned" to control feedback, and not tuned to the radio frequency oscillations).

14. Because of the small capacity in the tube, this circuit is adapted best to high frequency reception. If the variometers have appreciable distributed capacity, the advantage of this circuit may be lost. This circuit is used also for "autodyne" reception.

15. **OSCILLATING VACUUM TUBE DETECTION OR AUTODYNE RECEPTION.** Figure 1 is an inductive coupled regenerative circuit that may be used for the "autodyne" method of "beat" reception. This figure is the same as that referred to in the autodyne method under the heading of "BEAT RECEPTION," Par. 17, Chapter VIII. It was stated that the Vacuum tube when used in a regenerative circuit could be made to produce C.W. oscillations if the coupling between the coils L_3 and L_2 were sufficiently close. These oscillations will have the resonant radio frequency of

the grid circuit and the latter may be varied by changing the setting of C_2. With the proper coupling then by turning L_3, the circuit is subject to two frequencies, that of the incoming signal and that of the oscillations generated by the tube. If the setting of C_2 is such as to produce a **difference** of frequencies equal to an **audio** frequency the plate current through the telephone will vary at this audio or "beat" frequency and the pitch of the note in the phone will correspond to the beat frequency. Thus the note may be varied by the operator. This method is known as **autodyne reception.** The distinction in the term regeneration and autodyne is that in the former the circuit does not oscillate while in the latter case the circuit does oscillate. In the autodyne method of beat reception the one vacuum tube used functions both as the source of continuous wave oscillations and as a rectifier.

16. **HETERODYNE RECEPTION.** When the source of continuous wave oscillation is separate, we have the "heterodyne" method of beat reception which has many advantages over the autodyne. Figure 12, Chapter VIII is a circuit for heterodyne reception in which the local source of radio frequency oscillation may be a vacuum tube or an alternator and the detector is a crystal detector. Both the detector and the local source of radio frequency oscillations are generally vacuum tube circuits.

COMPARISON OF AUTODYNE AND HETERODYNE RECEPTION

17. Heterodyne reception is more sensitive than autodyne. In the latter the same tube acts both as a detector and as a source of C.W. oscillations. In the autodyne method the antenna is tuned to the frequency of the incoming oscillations; whereas in Fig. 1, the L_2C_2 circuit, controlling the locally generated frequency, is tuned to a frequency slightly different. This is due to the fact that the self sustained oscillations in the tube must be different in frequency from the incoming oscillations in order that beats may be produced. Therefore since the primary and secondary of Fig. 1 are not in resonance there is a reduction in signal strength and also in the selectivity of the set.

18. In the heterodyne method which employs separate vacuum tubes as a detector and as a source of continuous wave oscillations the tuning is sharper and the selectivity is improved. In the autodyne methodt he coupling must be tight to make the tube oscillate, whereas in the heterodyne the receiving circuit is not disturbed by changing the frequency of the oscillations of the oscillating tube. The beat frequency may be changed without retuning.

19. Both methods have in common the property that the pitch of the note may be varied to suit the sensitiveness of the telephone diaphragm or that of the operator's ear.

20. Interference is less troublesome with the heterodyne than with the autodyne method since the beat frequency may be changed with the former method without disturbing the tuning. As long as the beat frequency is within the range of audibility it may be made considerably higher or lower to distinguish the desired signal from the interfering note.

21. Heterodyne is more sensitive than autodyne. Heterodyne will give a response when the energy received has the very small value of 0.015 micromicrowatt.

22. The simple heterodyne method is not well adapted to reception of damped waves, or modulated C.W. such as are used in radiotelephony, since these waves have several frequencies which result in a number of beat frequencies producing a "mushy" note.

23. Autodyne reception requires but one tube; heterodyne requires two vacuum tubes or one vacuum tube and a crystal rectifier. In the heterodyne system one more tuning adjustment is required than in the autodyne.

24. Considering the foregoing advantages and disadvantages, the heterodyne method of beat reception is superior to the autodyne method. This superiority is greatest at the low radio frequencies. At high radio frequencies the detuning necessary to produce beats of about one thousand per second is of no importance. Therefore, in the case of the autodyne method the greater simplicity of tuning, due to one less control, causes the general adoption of the latter method for high radio frequencies.

25. **THE HETERODYNE FREQUENCY METER.** When providing many channels for simultaneous radio communication it is highly desirable that each transmitter should be required to operate exactly on its assigned frequency. Since absolute accuracy is unobtainable a definite tolerance figure (stating how close to the assigned value one must be to be acceptable) is naturally set up. It might be stated that the transmitter frequency must be maintained within a certain percentage of the assigned value, but this is not satisfactory since a small fixed percentage would be but a few cycles on the lowest radio frequencies and at the same time might be many kilocycles at the higher radio frequencies. A satisfactory solution is obtained by specifying that the actual frequency must come within a certain number of cycles per second of the assigned value.

26. If 350 cycles per second is taken as the tolerance and it is assumed that a good frequency meter of the simple tuned circuit type can be depended on to within no better than one-half of one percent, it appears that the simple frequency meter could not be used beyond 70 kcs. Since this condition actually is coming to exist it has become necessary to provide a type of frequency meter which may be set closer than the tolerance (350 cycles, or whatever it is). A type of meter which can be set to within a few cycles per second is provided by using a simple vacuum tube generator circuit with telephones so that it can be used as an autodyne receiver as well as a generator. While it is quite simple to set the frequency generated by this circuit to within a few cycles of the frequency generated by some other C.W. source (or vice versa) the ordinary type of autodyne circuit is of little use as an accurate frequency meter because the calibration is apt not to stay constant even long enough to complete a calibration. Many things, such as plate voltage, filament current, the nearness of the meter to surrounding objects, the temperature of the meter and the particular headset used may cause the frequency generated with a given setting of the meter to vary seriously.

27. A type of autodyne circuit in which many precautions have been taken to minimize the variation of frequency generated (so long as the setting of the meter remains constant) is known as a heterodyne frequency meter.

28. **APPLICATIONS.** The heterodyne frequency meter is intended primarily for use only with pure C.W. It may be used with other forms of radiation but with a lesser degree of accuracy. It is used for determining frequencies in connection with a transmitter and in connection with a receiver. In either case, there are three general ranges of frequencies which must be discussed. **First,** those frequencies whose fundamentals lie within the range of the meter; **second,** those whose fundamentals are higher than the range of the meter; and **third,** those whose fundamentals are below the range of the meter. The possibility of getting these last two determinations depend upon the presence of harmonics (of the fundamental frequencies) in transmitters and receivers and in the heterodyne frequency meter itself.

29. **ADJUSTMENT OF METER. First,** turn on filament and close switch connecting coil which includes frequency band desired. **Second,** test to see if meter is oscillating by pressing on test button (which produces a double click in phones if meter is oscillating) or by noting deflection of grid current meter if one is provided. **Third,** couple meter to circuit whose frequency is to be measured—usually, a loose coupling is desired, but tight coupling may be obtained by clipping the pull-out coupling cord direct to other circuit. **Fourth,** vary capacity of tuning condenser of meter until a note is heard in phones. When a point is reached where the frequencies generated by the two circuits differ by only a few kilocycles a high pitch note will be heard. Further decrease in the difference of frequency will then reduce the pitch of the note. The pitch will become lower and lower until it becomes inaudible, due either to passing below the limit of audibility or due to the two generators pulling into synchronism, as they tend to do when generating very nearly the same frequency. In either case the frequency of the meter can be changed to find the settings on either side of the zero beat (silent) zone where a beat note just becomes audible. The desired reading (condenser setting) will then be half way between these points. This condenser setting must be referred to the meter's calibration curves from which the measured frequency is obtained in kilocycles.

30. **USE WITH A TRANSMITTER OF APPROXIMATELY KNOWN FREQUENCY. CASE I.—Where Frequency to be Measured Lies Within the Range of the Meter.** Couple the meter loosely to the antenna system of the transmitter. Search for zero beat points.

If there are many signals of considerable strength loosen the coupling until only one of appreciable strength is found. The corresponding zero beat point will be the desired frequency. Note that if the coupling is too close the meter may pull into step with the transmitter when the adjustment is far from the zero beat position. This results in finding no zero beat position. In this case a noise will usually be heard in the neighborhood where the zero beat ought to occur.

31. In all cases where the fundamental of unknown frequency does not lie within the range of the meter, the determination should be made to depend upon zero beats obtained between the **fundamental** in one and a **harmonic** in the other. Beats between a harmonic of one and a harmonic of the other ("fractional harmonics") are perfectly possible but generally are weaker than those mentioned above (they may be used in making checks when in doubt, but generally should be avoided). Let f_1 be the frequency generated by the meter, and f_2 the frequency generated by a transmitter (or oscillating receiver) at the time when a zero beat point has been located. The occurrence of zero beats proves that $mf_1 = nf_2$, where theoretically m and n are any integers. Practically, m and n are limited to moderately small values. As a very rough indication it might be said that the maximum value of m is around 5 while the maximum value of n is around 50. Note that f_1 is the frequency which will be found by referring to the calibration curve of the meter. Now, solving the preceding relation, the desired fundamental frequency, f_2, is equal to m/n times f_1. This gives the rough indication that the actual fundamental frequency is apt to be between 0.02 and 5 times the reading found on the calibration curve.

32. **CASE II. Where frequency to be measured lies above range of meter.** In this case beats between the **fundamental of the transmitter** and various **harmonics of the meter** are desired. Therefore, couple meter to the transmitter's antenna as this will reduce the strength of transmitted harmonics. Also, use a degree of coupling which will produce only a moderate number of zero beat points. Measure any strong zero beat point. Knowing the approximate fundamental frequency of the transmitter determine by inspection which harmonic (of the meter) has been measured and multiply the value found on calibration curve by m, which is the number of the harmonic being used.

33. **CASE III. Where frequency to be measured lies below range of meter.** In this case, beats between the **fundamental of the meter** and various **harmonics of the transmitter** are desired. As the harmonics in the transmitter itself are eliminated as far as practicable before sending the power out on the antenna, the strength of the harmonics in the antenna system will be very much less than the strength of the fundamental. For this reason it may be necessary to couple (rather loosely) to the plate circuit of the transmitter, rather than to the antenna. Measure any one of the zero beat points where a strong signal is obtained. By inspection, determine which harmonic (of transmitter) has been measured, and divide the value found on calibration curve by n, which is the number of the harmonic being used.

34. **USE WITH TRANSMITTER OF TOTALLY UNKNOWN FREQUENCY.** It will first be necessary to determine whether this unknown fundamental frequency is above or below the range of the meter. Couple meter to transmitter as explained above and measure the zero beat points for several (adjacent) combinations which give nearly the same strength of beat. Tabulate all these measurements and correct to equivalent wave length in meters. Assuming the unknown frequency to be above the scale of the meter, there should be a **constant difference in wave lengths** between adjacent zero beat points. The unknown fundamental will be equal to the constant difference obtained, and will also be equal to the least common multiple of the tabulated frequencies. This value should be checked as under Case II above. If, however, the unknown frequency is **below** the range of the meter this fact will be evident since, if the values found represent adjacent beats with each harmonic, their **frequency difference** should be constant and should be equal to the desired frequency. This desired frequency will also be the highest common divisor of all the tabulated frequencies. The result should be checked as in Case III above.

35. While all of the above precedures have had to do with the measurement of unknown frequencies, it is obvious that a transmitter can be adjusted to a desired frequency by reversing the procedure. When there is doubt concerning the approximate value of a frequency to be measured, the

work connected with determining it may be substantially shortened by first making a preliminary survey with the old style simple frequency meter.

36. **USE WITH A RECEIVING CIRCUIT.** Assume that a receiving circuit has been tuned to receive a signal from some external source of unknown frequency and it is desired to ascertain this frequency. The meter may still be used as a receiver (as described above) if an audible signal can be obtained (from the self oscillations of the receiving set). However, this method is not practicable, as the modern Navy receivers are so heavily shielded that almost no signal can come through the shielding; also, when provided with r.f. amplifiers ahead of the oscillating stage very little of the oscillation strays back to the input. **The practical method** is to use the meter as a transmitter loosely coupled to (antenna circuit of) receiver after the receiver has been set to zero beat with the incoming signal. By then adjusting the frequency transmitted **by the meter** until the zero beat is again obtained on headset of **receiver** the unknown frequency will have been obtained as indicated on calibration curve of the meter.

37. **USE IN ADJUSTING RECEIVER TO RECEIVE DESIRED FREQUENCY.** In order to set a receiver to any desired frequency, loosely couple meter to receiver antenna system, and by reference to calibration curve set meter to desired frequency. Start self oscillations in meter, and **tune receiver** until zero beat point is ascertained. Then slightly detune receiver until strong audible note, say of 1000 cycles, is obtained so that, without further adjustment a good beat note will be heard immediately when a signal comes in from a distance.

CHAPTER XII

CONTROL OF SELF OSCILLATIONS IN MULTIPLE STAGE AMPLIFICATION

1. A separate chapter is devoted to the control of self oscillations in multiple stage amplification for the reason that when more than two or three stages of amplification are employed, difficulties are encountered which must be eliminated before satisfactory results can be obtained. Troublesome regenerative effects occur due to stray feed back couplings that are inherent in all radio circuits.

2. **REGENERATION** is caused by feed back from the plate circuit to the grid circuit through some form of resistance, inductive, or capacity coupling. If this coupling is made large enough and has the proper phase, the feed back will cause continuous oscillation in the grid circuit as pointed out in Par. 6, Chapter XI. This causes various "squealing" and "howling" sounds in the phones and completely drowns out the signal.

3. **COUPLING EFFECTS.** Since coupling exists between two circuits whenever they have any resistance, inductance, or capacity in common, it can be readily seen that there are numerous coupling effects between the different parts and circuits of a radio set that cannot be entirely eliminated.

4. The resistance coupling effects occur in the common leads and the common battery.

5. The inductive coupling effects occur wherever the magnetic field of any part of a circuit links with another part of the circuit. This may be due to the fields of inductance coils or even to that of simple parallel conductors.

6. There is distributed capacity between the turns of inductance coils, and even between the leads of different circuits. The most important of all the stray coupling effects is that due to capacity between the grid and plate of a vacuum tube.

7. **SHIELDING.** In order to eliminate the various coupling effects as much as possible, tin or copper shields are placed between the various parts of the circuits where possible. The whole set is also usually inclosed in a sheet copper or tin foil lined case, and this lining is grounded in order to eliminate the outside capacity effects such as that caused by the hand or the body. Shielding cannot be used to eliminate the capacity effect of the tube however, and consequently most of the trouble is due to the capacity coupling feed back effect between the grid and the plate.

8. **UNIDIRECTIONAL CURRENT THROUGH A V.T.** It is well to distinguish here between the direct current and the alternating current that flows through the tube part of the plate circuit. The **resistance** of the tube is composed almost entirely of the space between the plate and filament which becomes a conductor when electrons flow between them. Even under these circumstances however, the resistance of this gap is very large—roughly, between 5,000 and 25,000 ohms. This is the **only** path for the direct current, and when there is no emission of electrons, there can be no direct current.

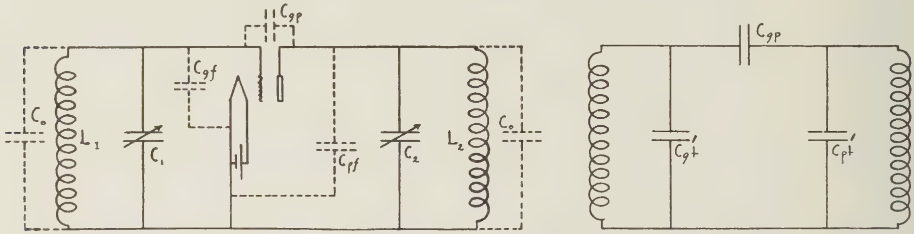
9. **ALTERNATING CURRENT THROUGH A V.T.** In addition to the above current path, we have the plate, grid, and filament acting as plates of condensers with the space between them acting as a dielectric. The capacity reactance of this combination may be much smaller with the high frequencies than the plain resistance of the gap mentioned in the preceding paragraph, and a considerable part of the AC components of the current would accordingly take the former path in preference to the latter. The tube could be considered as a circuit consisting of resistance in parallel with condensers—somewhat similar to the action of a grid leak and condenser where the direct current flows through the resistance and the larger portion of the alternating current through the condenser, the proportion depending upon the relative values of the resistance and reactances.

10. **CAPACITY COUPLING EFFECT OF A VACUUM TUBE.** Under the above circumstances the capacity coupling effect of a vacuum tube may be quite large. Current flowing through a condenser is given by

$$I=\frac{E}{X_c} \text{ and since } X_c=\frac{1}{2\pi fC} \text{ we have } I=2\pi fCE.$$

A study of this equation shows that with capacity and voltage constant, the value of the current varies directly with the frequency.

11. In Fig. 1 (a) is shown a common variety of vacuum tube circuit. In addition to the condensers C_1 and C_2 which may (or may not) be used with such a circuit, five capacities are shown by dotted lines. As explained in the following description, these represent the distributed capacities of the various parts of the circuit. C_{gf}, C_{gp}, and C_{pf} are respectively, the inter-electrode capacities between grid and filament, grid and plate, and plate and filament. C_0 represents the distributed capacity of a coil and its connecting leads.



(a) Vacuum Tube Circuit with Capacities between Various Parts Represented by Condensers in Dotted Lines.

(b) Equivalent Circuit with Capacities Represented by Three Condensers.

FIG. 1.—Vacuum Tube Circuit with Capacities of Various Parts Represented by Condensers.

12. Brief inspection will show that the grid oscillating circuit is made up of inductance L_1 in series with a capacity consisting of C_0, C_1, and C_{gf} in parallel, while the plate oscillating circuit is made up of L_2 in series with a capacity consisting of C_0, C_2, and C_{pf} in parallel. These two circuits are coupled through C_{gp}. The equivalent circuit with lumped capacities C'_{gf} and C'_{pf} is shown in Fig. 1 (b). The coefficient of coupling in a circuit such as this is given as being

$$k=\frac{C_{gp}}{\sqrt{(C'_{gf}+C_{gp})\ (C'_{pf}+C_{gp})}}$$

13. By inspection it is seen that the coupling depends upon the relative sizes of C_{gp}, C'_{pf} and C'_{gf}, see Fig. 1 b. As it is common practice to use small capacities to tune circuits to high frequencies, the coupling between plate and grid circuit is correspondingly higher in such circuits.

14. In amplifier circuits using only small tuning capacities there will be a strong feed back. This feed back may have a component in phase with the incoming signal; if so, its effect is additive. This component in phase with the incoming signal is obtained with an inductive load in the plate circuit. (See chapter X.)

15. The feed back coupling effect between the plate and the grid of a vacuum tube is made use of for regeneration in some sets, such a one being described in Paragraph 12 and Fig. 3 of Chapter XI. The difficulty with the feed back lies in the fact that it may be sufficient to start self oscillation in the tube.

16. For reception with an ordinary head set it is common practice to use one or two stages of audio frequency amplification, while with a loud speaker three or even four stages may be used. Beyond three stages of audio frequency amplification, special precautions are required to prevent self sustained oscillations.

17. For the reception of signals so weak that they will produce practically no results if applied directly to the detector, radio frequency amplification must be used. Fig. 2 shows a five tube

receiving set without any arrangement for eliminating the troublesome regenerative effect other than what would be afforded by shielding. This set would undoubtedly give trouble due to self oscillation and some additional arrangement is necessary to prevent this.

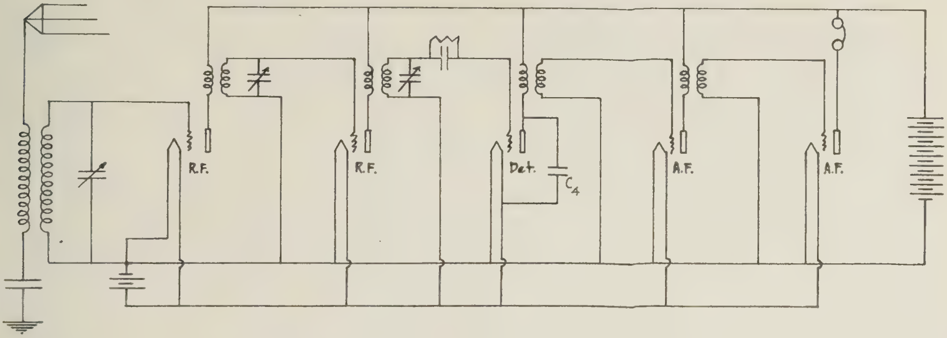


Fig. 2.—Radio Receiving Circuit with Two Stages of Audio and Two of Radio Frequency Amplification.

18. The three principal methods of accomplishing this are:
   (a) The Stabilizer or Potentiometer Method.
   (b) The Negative Feed Back Method.
   (c) The Super-Heterodyne Method.

19. The **STABILIZER** (or **POTENTIOMETER**) **METHOD.** As explained in Paragraph 39, Chapter X, the grid of an amplifier tube is kept negative by being connected to the negative terminal of the filament battery, provided there is a rheostat in the negative leg of the filament circuit, and in this condition the grid repels the electrons. If we gradually change its potential from negative to a positive value, its opposition to the electrons will gradually decrease until finally it will attract them and an appreciable current will flow in the grid circuit. This change can be made by connecting a potentiometer across the filament battery with a sliding contact connected to the grid circuit as shown in Figure 3. This arrangement is known as a **Stabilizer.** An inspection of this figure shows that moving contact "X" from the negative side of the battery towards the positive side has the effect of increasing the grid current $\mathbf{I}_g$ and therefore increasing the losses in the grid circuit RI_g. (See also Figure 18 Chapter IX).

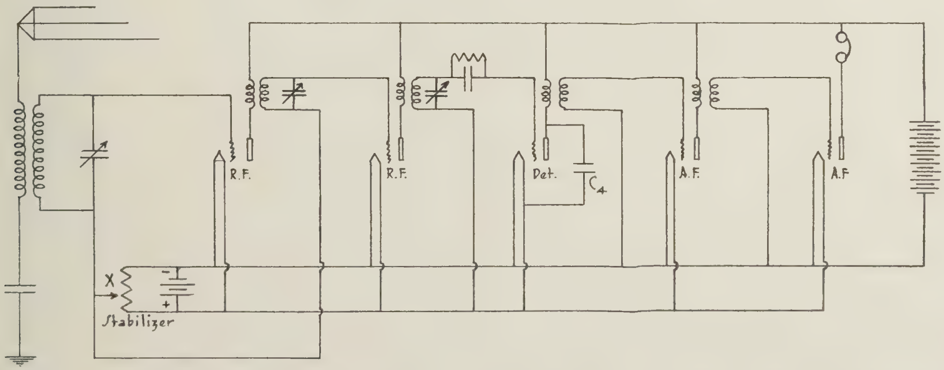


Fig. 3.—Receiving Set Consisting of Two Stages of r.f., and Two Stages of a.f. Amplification Fitted with Stabilizer.

20. This increased loss occurs inside the tube in the conduction path between grid and filament which is provided whenever the grid becomes positive. The more highly positive the grid, the lower the resistance of this path and consequently the greater the loss. Now if oscillations occur in the

circuit due to the feed back, all that is necessary to stop them is to make the resistance of this path low enough so that it will absorb a little more energy than is fed back. The amplification of the tube will of course be reduced in doing this.

21. It should also be noticed that if the grid is made **positive,** distortion will occur as explained in Paragraph 39 of Chapter X. Distortion occurring in a single cycle of the radio-frequency does not necessarily introduce appreciable distortion in the audio frequency output of the detector.

22. The arrangement of a five tube set with a stabilizer is shown in Fig. 3 above. This arrangement is identical with that of Fig. 2 except that a potentiometer is connected across the filament battery and the grid leads of the two radio frequency amplifier tubes are connected to the movable contact of the stabilizer instead of to the negative side of the battery.

23. **NEGATIVE FEED BACK METHOD.** In explaining the principle of regeneration, it was pointed out that the feed back must be **in phase** with the incoming oscillations in order to add to its strength. If it was fed back **180° out of phase,** the amplitude of the oscillations would decrease. The plate-grid capacity coupling may cause a component of current **in phase** with the incoming signal. If we arrange an additional feed back 180° out of phase with it and equal in amount, we can balance or neutralize the other feed back and control the self oscillations of the tube in this way. This additional feed back can be either inductively or capacitively coupled.

24. If we coupled the plate circuit of a tube back to the grid circuit as in the regenerative circuit of Fig. 1, Chapter XI, but **with the connections to L_3 reversed,** the feed back would oppose the incoming oscillations. If we made this back coupling just sufficient to compensate for the **positive** feed back of the tube, the two would neutralize each other and there would be no tendency towards self oscillation. This is the principle of the **"Superdyne"** circuit.

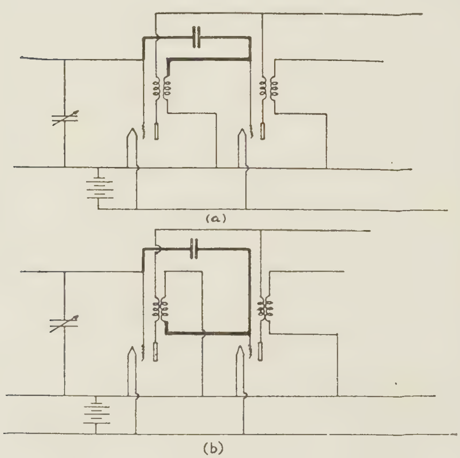


FIG. 4.—Principle of the Neutrodyne Circuit.

25. Similarly, if we connected a condenser across the grid circuits of the first two tubes of Fig. 2 as shown in Fig. 4 (*a*), this condenser would serve as a capacity coupling which would feed back the grid oscillations of the second tube **in phase** with the feed back through the inter-electrode capacity. If now the connections of the secondary of the transformer were reversed as shown in Fig. 4 (*b*), the feed back would be 180° out of phase with the feed back through the inter-electrode capacity. By adjusting the neutralizing condenser so that its feed back equals that of the tube, a balance between the two is obtained and self oscillation is prevented. This is the principle of the **"Neutrodyne"** circuit.

26. Fig. 5 shows a five tube Neutrodyne circuit with the neutralizing condensers indicated. Instead of connecting these condensers across the grid circuits, they could be connected across the plate circuits and the operation would be similar. The grid circuit connection is the one generally used.

27. **THE SUPER-HETERODYNE CIRCUIT.** Another method of avoiding self oscillation is based on a different principle. The use of a separate source of oscillations to reduce the radio frequency oscillations to an audible frequency by the beat method has been described under **Heterodyne Reception** (Par. 16, Chap. VIII). Since the capacity feed back of a tube is normally less at lower frequencies (See Par. 9) we could reduce it by lowering the frequency. Reducing the received frequency by the heterodyne method to **audio** frequencies is impracticable **in radio telephony,** as distortion would occur.

28. Major Armstrong, U.S.A., conceived the idea of using the heterodyne to reduce the incoming

high radio frequencies to **lower** radio frequencies by the beat method. These lower radio frequencies are sufficiently low to reduce considerably the effect of the tube coupling, but are still high enough to permit their being detected and reduced to **audio** frequencies without distortion of the sounds. Thus if music is being broadcast at a frequency of 3,000 kcs., a heterodyne arrangement can reduce this to a beat frequency of 100 kcs. This is sufficiently high to prevent distortion, and yet the reduction in the frequency will so reduce the coupling effect of the tubes that the feed back currents are too small to cause them to oscillate. This enables several stages of radio frequency amplification to be used without causing self oscillation.

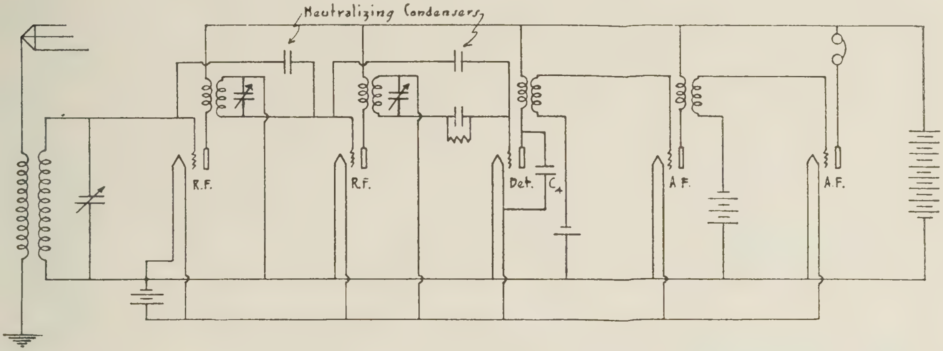


FIG. 5.—Five Tube Neutrodyne Circuit.

29. A separate vacuum tube is used as the heterodyne and this is coupled to the grid circuit of the first detector. The first tube of the receiving circuit is a detector or rectifier. The plate circuit of this tube will have a direct current, an amplified reproduction of the two radio frequency inputs, and finally a lower radio frequency component due to the rectification of the beats between the higher radio frequencies. The high radio frequencies and any audio frequency component, if it exists, are now discarded, while the lower radio (beat) frequencies are transferred to an amplifier tube for amplification.

30. This amplifier may contain from two to four stages, and the output of this intermediate frequency amplifier will then be detected, this time the output of the detector being **audio** frequency. Audio frequency amplification can then be added.

31. **COMPARISON OF DIFFERENT METHODS OF PREVENTING SELF OSCILLATION.** There is very little to choose between the Stabilizer Method and the Negative Feed Back Method. The Neutrodyne Circuit is probably the better of the two. Neither of the two will give as good results for long distance reception as the super-heterodyne. The latter also has the advantage of greater selectivity, this being obtained by changing the beat frequency as explained for the plain heterodyne reception in Paragraph 16, Chapter VIII. The principal disadvantages of the superheterodyne are its high cost and the fact that it responds appreciably in several different frequency bands widely separated from the desired one, due to the harmonic frequencies of the oscillator tube.

32. **REFLEX AMPLIFICATION.** In the reflex method of amplification, the same vacuum tube is used to amplify both r.f. and a.f. currents. Fig. 6 shows a scheme of connections in which one vacuum tube is used

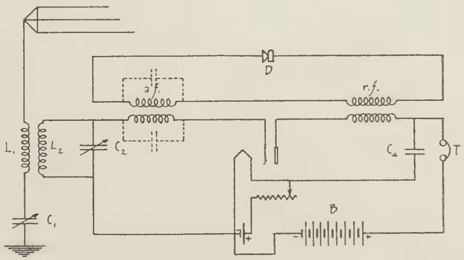


FIG. 6.—Reflex Receiving Circuit with One Vacuum Tube and Crystal Detector.

with a crystal rectifier. The incoming r.f. oscillations are amplified in the tube. The amplified r.f. variations of the plate current of the tube are coupled through the r.f. transformer to the crystal rectifier circuit. The audio frequency pulses of current in the latter are fed back through the audio frequency transformer to the grid circuit of the tube where they are again amplified and produce an audible sound in the telephones. Note that the tube is not used at all as a detector in this circuit. Also, while both r.f. and a.f. oscillations occur in the plate circuit, only the latter pass through and act on the telephone receiver, the r.f. oscillations passing through C_4.

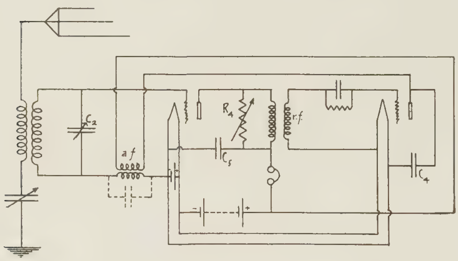


Fig. 7.—Reflex Receiving Circuit Using Two Vacuum Tubes.

33. The same principle holds when a second V.T. is used as a rectifier instead of a crystal. The diagram of such a circuit is illustrated in Fig. 7 which needs no further explanation except to note that a common battery is used for the filaments of both tubes and also a common plate battery.

34. In this type of circuit a potentiometer method of controlling oscillations is not satisfactory since distortion and inefficient amplification are produced in the audio frequency stage when the grid is operated with a positive bias. The radio frequency oscillations in this circuit are controlled by the large non-inductive variable resistance R_4. This can be reduced to a point where the radio-frequency losses occurring in it are sufficient to prevent self-oscillation.

35. The main advantage of reflex amplification is the smaller number of tubes required for a certain amplification. This fact makes it particularly well adapted to portable equipment due to minimizing battery equipment. The maximum output from any particular tube is limited. If this output is divided between two frequencies as in the reflex circuit, then it should be obvious that the maximum possible output on either one of these frequencies will be less than this limiting value. This is one of the principal disadvantages of the reflex set.

CHAPTER XIII

THE THREE ELEMENT VACUUM TUBE USED AS A TRANSMITTER

1. **OSCILLATOR ACTION OF THE THREE ELECTRODE VACUUM TUBE.** In Par. 6, Chapter XI, under regeneration, the statement was made that if too much energy was fed back from the plate circuit to the grid circuit in Figure 1, Chapter XI, that the vacuum tube would become **"self oscillating"** even if there were no incoming oscillations impressed on the grid circuit.

2. This regenerative circuit or any other regenerative circuit can be made to generate spontaneous oscillations if it be so arranged that any **change in grid voltage** makes a **change in plate current** of such magnitude and in proper phase so that there is induced in the grid circuit a **larger voltage** than that originally acting thus causing the oscillations to build up.

3. The action of the escapement of a clock in releasing the energy stored by the clock spring is similar to the action of the grid of the tube in a vacuum tube generating circuit in releasing the energy stored in the plate battery. In the clock, the pendulum or balance wheel as it oscillates back and forth controls the escapement. In the vacuum tube generating circuit the oscillations in the oscillating circuit accomplish the same thing. In either case when the device is once started the oscillations will continue with increasing amplitude until resistance or friction losses use up energy as fast as it is released.

4. **ANALOGY OF THE OSCILLATING TUBE AND CLOCK.** In the case of the vacuum tube generating circuit, we have electrical oscillations which correspond to the mechanical oscillations of the pendulum or balance wheel in the clock. In each case, the energy released from the supply stored with the device serves to cause the oscillations to continue to occur. In each case some useful load may be added to the oscillating device without stopping the oscillations, and in each case, if the load is made continually greater, a point will be reached when further increase in load will cause the oscillations to stop altogether. The tube circuit, unlike the clock, may be started into oscillation by the merest infinitesimal oscillation, such as might be due to the inherent tiny fluctuations of the plate current, in other words, it is practically impossibleto have a vacuum tube circuit in condition to oscillate and yet have it continue to remain in a nonoscillating condition.

5. The actual operation of the tube is quite like its action as a regenerative amplifier, as it actually amplifies the small amount of energy transferred from the plate to the grid circuit. In the regenerative amplifier the feedback is not quite sufficient to maintain the oscillations. In the vacuum tube generator, when the oscillations are of small magnitude the feedback is more than sufficient to maintain the existing power supply to the grid. The oscillations will continue to build up in magnitude until the **average** slope of the part of the plate current-grid voltage characteristic curve (See Fig. 1) in use has decreased to such an extent that the amplification resulting is only just sufficient to maintain the oscillations at the then existing amplitude.

6. **CHARACTERISTIC CURVES.** In explaining certain conditions in connection with operation of a vacuum tube reference will be made to the "instantaneous operating point." In practical operation of a vacuum tube there must be a load in the plate circuit. As a result of this the plate voltage changes as the grid voltage varies. At any particular instant there is a certain plate current and grid voltage. These two coordinates determine a point which is known as the instantaneous operating point. If there were no load in the plate circuit (i.e. load impedance equals zero) the instantaneous operating point would travel along the "static" characteristic. Since there must be a load impedance, the voltage applied to the plate will vary as the grid voltage is varied. As a result of this plate voltage variation the instantaneous operating point departs from a static characteristic and travels along another curve known as a dynamic characteristic. The dynamic characteristic then shows how the plate current will vary with variation of grid voltage when a particular load impedance (for which the characteristic was constructed) is used. (See Fig. 8, chapter X.)

The above statement may be further amplified from a mathematical point of view by recalling

that with a load, the voltage actually applied to the plate will vary in accordance with the condition

$$e_p = E_B - i_p Z.$$

That is, as the plate current varies (E_B remaining constant) e_p also varies. This equation shows that as the plate current varies the plate voltage will vary in an opposite manner. In practice the plate current variation is caused by a grid voltage variation.

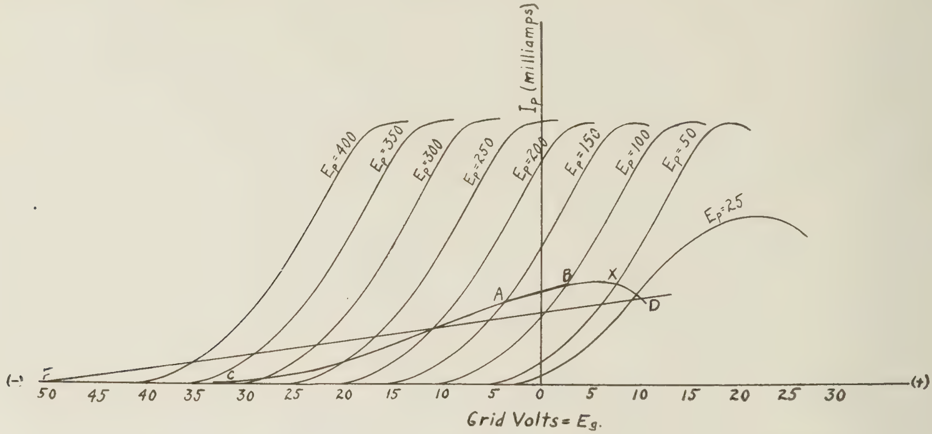


FIG. 1.—(Ip-Eg) Static and Dyamic Characteristic Curves of a Three-Element Vacuum Tube.

7. The amplification produced by a tube when small amplitude oscillations are impressed on the grid depends among other things upon the slope of path described by the instantaneous operating point. That is, it depends upon the slope of the portion of the dynamic characteristic along which this operating point travels. For small amplitude of applied grid voltage this will be approximately a straight line as shown at A B in Figure 1. Since the dynamic characteristic is not a straight line, if large alternating current voltages are applied to the grid the slope of the path of the operating point changes greatly within a cycle. To the left of point C the slope of the characteristic is zero, to the right of X the slope reverses, as a consequence, voltages which pass beyond C and X cause a large decrease in the **average** slope of the path of the operating point. The line F D shows this for a grid voltage which runs from -50 volts to $+$ 10 volts. This decrease in slope gives a decrease in amplification. This decrease in amplification is the thing which limits the amplitude of the generated oscillation.

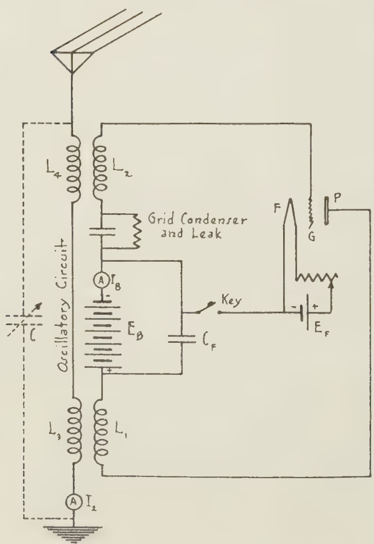


FIG. 2.—Meissner Circuit.

8. **TYPICAL OSCILLATING VACUUM TUBE CIRCUIT.** A typical circuit for generating oscillations with vacuum tubes is the Meissner circuit (See Figure 2). This is one of the earliest circuits, but is being employed to a considerable extent in modern transmitting tube apparatus.

9. The oscillating circuit is made up of coils L_4 and L_3 and the capacity C. In a transmitter the capacity C would be replaced by the capacity of the antenna, as indicated in Figure 2. The plate circuit of the tube will be

seen to contain the coil L_1 while L_2 is included in the grid circuit of the tube. Each of these coils is coupled to a corresponding coil in the oscillating circuit.

10. Let it be assumed that feeble oscillations occur in the oscillatory circuit. These oscillations will induce an alternating voltage in coil L_2 which will act upon the grid, producing variations in the plate current flowing through L_1, and these will produce an alternating voltage in the coil L_3, which, with the proper sign of coupling, will reinforce the original oscillations, causing them to increase in amplitude.

11. The increased oscillations will induce a still greater voltage in the coil L_2 and correspondingly greater variation in the current through L_1, leading to a further increase in the oscillatory current. This building up process continues until the tube cannot supply enough power to the oscillatory circuit to increase further the amplitude of the oscillations, and a constant alternating current will flow in the circuit having a frequency very nearly that of the natural period of the oscillatory circuit.

12. This frequency may vary from less than one per second to 10^9 per second. Ordinarily the final state is reached in a relatively small number of cycles after the tube is put into operation.

13. The condenser C_f is a large fixed condenser which serves as a path of low impedance across the plate battery for the high frequency alternations in the plate circuit. The grid condenser and leak are used as shown to improve the efficiency of operation and have nothing to do with detector action which does not occur in this circuit.

14. **PHASE REQUIREMENTS IN OSCILLATING TUBE CIRCUITS.** The alternating voltage on the grid of the tube produces the variations in the plate current when the tube is oscillating. The varying plate current can be considered to consist of two components, one a continuous current and the other a superimposed alternating current, as shown in Figure 3. The alternating component of the plate current supplies the voltage to the oscillatory circuit and sustains the oscillations.

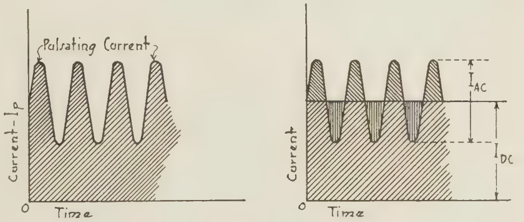


Fig. 3.—Analysis of Plate Current.

15. The voltage which works the grid is derived from the oscillatory circuit. The plate current increases when the grid is positive, therefore, the required coupling between the circuits is evidently the following. When the alternating component of the plate current reaches its maximum value in the positive direction which makes the total plate current high, the current produced in the oscillatory circuit must be acting through the grid coupling so as to bring the grid voltage to its maximum positive value. Thus the alternating plate current and the grid voltage must be in phase. This causes the phase angle between the grid voltage and plate voltage to be 180°.

16. A good check on whether the phase requirement is correct or not is that if the circuit is correctly arranged, an oscillation occurring in the oscillating circuit will tend to make the voltage of the grid negative with respect to the filament at the time that it tends to make the plate positive and vice versa. This requirement is met in the circuit of Fig. 6.

17. If with inductive feedback the phase relation should be incorrect a reversal of the connections to any one coil will usually make it right.

18. **CONDITIONS FOR OSCILLATIONS.** In some cases, even when the circuit is such that the phase relations are correct, the tube will not generate oscillations. For example, a given tube will generate oscillations when the capacity in the oscillatory circuit is small but will not oscillate when the capacity is larger than a certain value. Also, increasing the resistance of the oscillatory circuit tends to stop the tube from generating oscillations, so that when the capacity is small the resistance can be higher and when the resistance is low a greater capacity can be used. When two vacuum tubes are connected in parallel, it is possible to get oscillations at higher values of capacity or resistance than when only one tube is used.

19. In some cases at short waves, the tube will refuse to oscillate at a low capacity value even when the connections are correct, or may even oscillate with the reverse connection from that which gives

oscillations at higher capacity values. This is caused by incorrect phase relations between the grid voltage and plate current resulting from the capacity of the coils, leads, and between the electrodes of the tube.

20. **CIRCUITS USED FOR GENERATING OSCILLATIONS.** Numerous circuits have been devised to produce oscillations, the "feed back" action being obtained by the use of direct coupling, by inductive coupling, or by electrostatic coupling from the plate back to the grid circuit.

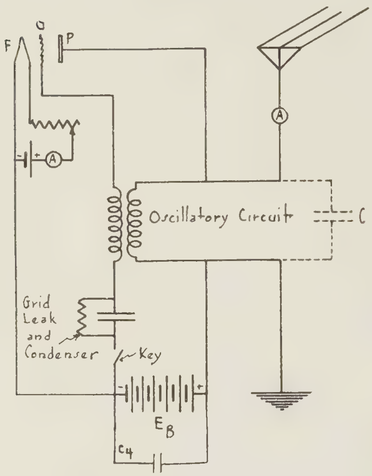


Fig. 4.—Vacuum Tube Generator, Oscillatory Circuit in Filament-Plate Circuit.

21. Figure 4 shows a generator circuit directly coupled to an antenna. The oscillatory circuit is in the filament-plate circuit, instead of being separate as in the Meissner circuit, and is inductively coupled to the grid circuit.

22. The operation of this circuit is somewhat different from that outlined above. Instead of transferring all of the energy necessary to sustain the oscillations from the plate to the grid circuit via a separate oscillatory circuit as in the preceding case, only an e.m.f. which serves as a control is here transferred. Thus, the grid circuit plays a similar part to that of the slide valve in a reciprocating engine. The path of the current flow within the tube from plate to filament may be regarded as a variable resistance, the value of which depends upon the potential of the grid. If the potential of the grid is alternating, the resistance will increase and decrease accordingly, thus throwing an alternating e.m.f. upon the oscillatory circuit which is in series with the resistance. The antenna and ground may be replaced by the condenser C making the closed oscillatory circuit in the figure.

23. One type of circuit that employs direct coupling from the plate circuit back to the grid circuit is **The Hartley Circuit.** This circuit may be considered as a modified Meissner Circuit wherein the coupling is direct inductive coupling instead of indirect inductive coupling. In Figure 5, the plate circuit of the vacuum tube is coupled directly to the oscillatory circuit through L_1. The oscillatory circuit is coupled to the grid circuit through L_2. The circuit operates as follows: the varying plate current induces a voltage across L_1 which causes a current to flow in the oscillatory circuit ($L_1L_2C_0$); this oscillating current induces a voltage across L_2 which in turn causes a current to flow in the grid circuit thereby controlling the grid potential which in turn controls the plate current. Thus, oscillations are maintained continuously. The grid leak and condenser are inserted to increase the efficiency of the hookup. Their use reduces the power loss, due to useless D.C. components of current in both the grid and plate circuits.

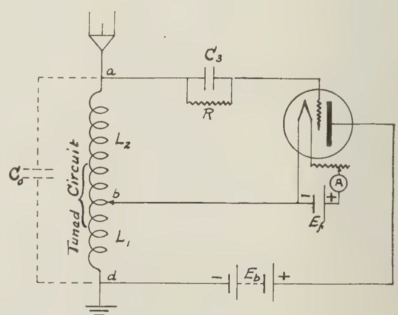


Fig. 5.—The Hartley Circuit.

24. In addition to the above types of circuits in which an electromagnetic coupling between plate and grid circuits is used to transfer electromotive forces from one to the other, there are also circuits in which electrostatic coupling is utilized. One type of capacitive coupling known as the Colpitt's circuit, is illustrated in Figure 6. In this circuit the tube supplies power to the oscillatory circuit by means of the voltage across the condenser C_p and power is extracted by the grid circuit by the voltage across C_g. With this type of circuit

the direct current power furnished by the plate battery or generator is connected in series with a radio-frequency choke coil directly from plate to filament. The inductance L_p prevents the radio frequency component of the plate current from going direct to the filament through the plate battery, and causes it to go through the oscillatory circuit on its way to the filament. The coupling between plate and grid circuits depends upon the ratio of C_g to C_p. The condenser C_1 is inserted between the plate and the oscillatory circuit to prevent the high positive potential of the plate from being impressed on the grid and to pass the radio frequency component of the plate current. When the vacuum tube is oscillating on its positive swing electrons flow to the grid and unless this current is permitted to flow away, the grid will become charged highly negative thereby stopping the oscillations. The resistance r and the choke coil L_g permit these grid charges to flow away without preventing the necessary radio frequency voltage variations from being applied to the grid. During operation the voltage drop across r tends to make the grid somewhat negative thereby leading to increased efficiency. This is called a "parallel feed" circuit since the source of direct current power, the output circuit, and the tube, are in parallel. If it is desired to use this circuit for transmitting, the condenser C_p can be replaced by the antenna and the ground, the ground being connected to the key side of C_p.

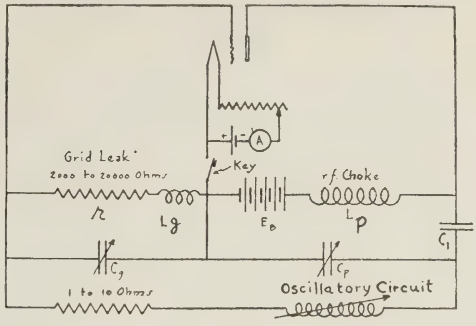


FIG. 6.—Vacuum Tube Generator Using Electrostatic Coupling.

25. Another type of electrostatic coupling is illustrated in Figure 7. In this circuit the condenser C_2 serves as the coupling. The inductances L_1 and L_2 should be variable and approximately equal and not inductively coupled to each other. C_f is a fixed condenser which serves as a path of small impedance or by-pass for the high frequency current around the plate battery. The frequency of the alternating current is determined primarily by the inductances L_1 and L_2 and the condensers C_1 and C_2. The parallel connections of C_1 and L_1 serves as an "absorbing" circuit, that is as C_1 is increased from a very low value, the current circulating around this circuit will increase up to a certain point and may considerably exceed the current in the other portions of the circuit. Variable condenser C_1 enables tuning of circuit C_1L_1 and thus obtaining maximum output.

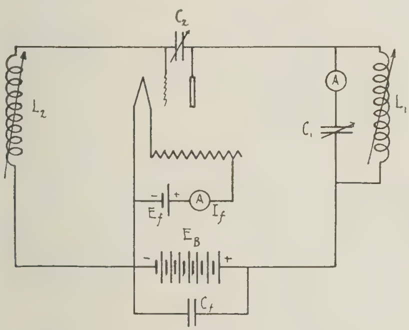


FIG. 7.—Vacuum Tube Generating Circuit in which Grid and Plate Circuits are Capacitively Coupled.

26. **ADJUSTMENT FOR MAXIMUM OUTPUT.** As pointed out before, the plate circuit of the tube applies the power to the oscillatory circuit. This latter circuit acts as the load and, in fact, is very nearly equivalent to a resistance load in the plate circuit of the vacuum tube. In order to obtain the maximum current in the oscillatory circuit it is necessary that the load be of the proper value to fit the vacuum tube.

27. **USE OF COUPLED CIRCUITS.** Coupled circuits in which both elements are tuned are rarely used with vacuum tubes. The Meissner circuit does not come under this heading because only one circuit is tuned. The objection is loss of efficiency and erratic operation. With close coupling between tuned circuits it is possible for oscillations of two different frequencies to occur. The vacuum tube can jump from one of these frequencies to the other; in fact, it is possible to adjust

the circuit so that the antenna current is high and definite wave length secured, and then find that, no keying, the current in the antenna will jump to a low value and have a widely different frequency.

28. **POSITION OF BATTERIES OR GENERATORS.** When an antenna is used with any of the direct coupled circuits the antenna ground is of necessity connected to some point on the tube circuit. It is desirable to connect the batteries or generators which supply the tube to the same grounded point in the circuit. The reason for this is that the batteries and generators have large capacities to ground, and unless the connections are made as indicated above, these capacities to ground will be put in parallel with a part of the oscillatory circuit and will cause loss of power and possibly prevent oscillations. Ordinarily, therefore, the batteries or generators and the antenna ground are connected adjacent to the filament.

29. **EFFICIENCY OF VACUUM TUBE GENERATOR.** The efficiency of a vacuum tube generator is generally defined in terms of the input power supplied by the plate battery and the output alternating current power in the oscillatory circuit. The power required to heat the filament is usually neglected, though in small tubes it may be several times the output power. The power supplied by the plate battery is the product of the direct current volts and direct current amperes. The output power is the product of the square of the alternating current times the resistance of the oscillatory circuit. The ratio of (alternating current output power) to (plate circuit input power) is the efficiency. For low power tubes this may be 15 to 30 per cent; for medium power tubes, 40 or 50 per cent. The maximum efficiency in high power tubes is about 70 per cent.

30. **METHOD OF RATING POWER.** The Navy rates tubes in terms of the output power. For example, the CW 931 tube is rated as a 5-watt tube. It should, therefore, supply one ampere into a five-ohm antenna, for 5 ohms times (1 ampere)^2 equals five watts. The normal plate supply is about 50 milliamperes at 350 volts, or 17.5 watts ($0.05\times350=17.5$). The efficiency is then 5/17.5 equals 0.29, or 29 per cent. Usually efficiency is sacrificed to some extent in order to obtain the maximum output from the tubes; at reduced output somewhat greater efficiencies are obtainable. The power in the plate circuit which is not used in generating oscillations is dissipated in heat in the plate of the tube. If the tube stops oscillating, then all of the plate circuit power is expended in heating the plate.

31. In low power tubes the plate of the tube can frequently be seen to heat up when oscillations stop. In high power tubes this heating can be sufficient to destroy the tube in a short time, hence it is necessary to maintain oscillations or immediately shut off the plate power supply.

32. **VARIATION OF OUTPUT WITH PLATE VOLTAGE.** The output of a tube is limited primarily by the total emission of electrons from the filament and the plate voltage, provided that the design is such that the plates do not become overheated and the vacuum is high. With a given plate voltage, however, only a limited amount of emission from the filament can be used; the higher the plate voltage the more emission is useful. On the other hand, with a given emission the output of the tube can be increased without limit by increasing the plate voltage, provided the tube will stand it. Thus high plate voltages are necessary for high powered tubes in order to keep down the filament power. In tungsten filament tubes the filament emission is usually limited, for at usual operating temperatures it requires considerable filament power to supply the heat required to liberate the electron. In the coated filament tube the emission for the same filament power is very much greater—usually a number of times greater—than is normally utilized.

33. When the filament emission is very great the output current varies practically in proportion to the plate voltage, while with insufficient emission the output current is roughly proportional to the square root of the plate voltage.

34. **SIZE, ADVANTAGES, AND POWER OF TUBES.** Tubes apparently can be built in any size for which there is commercial demand. The smallest power tube in extensive use in the Navy is a 50 watt tube. The largest single tube at present installed produces 20 KW output. Vacuum tube circuits produce a more nearly sinusoidal wave than arcs do. There is little or no mush produced by the vacuum tube. Transmission with a vacuum tube is more readily controlled. The vacuum tube is very much lighter than an arc set of the same size. (For example, a 1000 KW arc might weigh 100 tons while a 1000 KW tube might weigh 100 pounds). Vacuum tubes can be made in small sizes while 2 KW seems to be about the smallest practical arc. Vacuum tubes are readily used for radiophone while arcs are not. The efficiency of the vacuum tube in large sizes is higher than the arc. With the present design of tubes the upkeep on a tube set is much higher than on an arc set. In high powered tubes means must be provided for carrying away the heat. This is usually accomplished either by air blast or water cooling.

35. **QUARTZ CRYSTALS FOR OSCILLATORS.** The quartz crystal oscillators are usually cut in the form of square plates. These are cut from the natural quartz crystal, so that the plane of the plate is perpendicular to a lateral face of the natural crystal. In this case, the thickness of the plate is in the direction of the so-called electrical axis. The electrical field is applied in the direction of the electrical axis by placing the crystal between two metal plates. The crystal exhibits natural periods of mechanical vibration and when the frequency of the electrical field corresponds to a natural frequency of vibration of the crystal, the crystal vibrates strongly and pronounced resonance effects are observed in the electrical circuit. These frequencies are related to the dimensions of the plate, to the thickness and the breadth. The frequency is roughly given by the relation that the wavelength of the oscillation is 100 meters per millimeter of thickness or length. Thus a crystal 0.5 millimeter thick gives a wavelength of approximately 50 meters.

36. When the crystal plates are connected respectively to the grid and filament of a vacuum tube and a parallel coil and condenser of suitable values are inserted in the plate circuit, the tube will generate oscillations which are determined by a natural period of the crystal. These oscillations are very constant in frequency, show practically no variation when plate or filament voltages are varied, or when the tuning of the condenser in the plate circuit is changed. Such a system is suitable for a standard of frequency and also is a valuable master oscillator for a vacuum tube transmitter in particular at very high frequencies. At present several crystals which have been calibrated very accurately serve as frequency standards for the Navy. The frequency of these crystals has been determined to better than one-hundredth of one per cent. Three transmitters are now in use at Bellevue using crystal control, one of which puts 9 K.W. into the antenna, and all operating on high frequencies.

37. **THE MASTER OSCILLATOR POWER AMPLIFIER SYSTEM.** Vacuum tube transmitters, which have their oscillation generating circuit coupled directly to the antenna system have their frequency influenced by any change in the antenna system. The master-oscillator power-amplifier system provides means for reducing this effect. It consists of a master oscillator which determines the frequency to be generated and a radio frequency amplifier which when excited by the output of the master oscillator provides a larger power output. It also allows the relatively small output available directly from a quartz crystal oscillator to be amplified to provide large power output.

38. The power amplifier is of course a radio frequency vacuum tube amplifier. The circuits for such amplifiers have been discussed under Chapter XII. The principles are the same, the practice is modified by the fact that the tubes are operated with high voltages and powers and also near to the full capacity of the tube. It should be particularly noticed that the same problem of self oscillation is encountered here as in receiving amplifiers. The same principles serve to eliminate this.

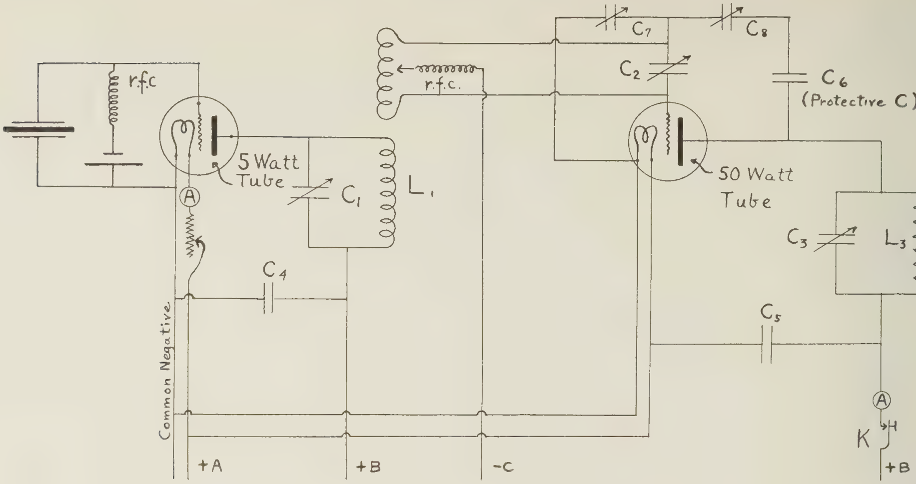


Fig. 8.—A Master-Oscillator, Power-Amplifier Circuit.

39. An elementary circuit showing general scheme of this circuit is shown in Figure 8.

Here is shown a power amplifier used to increase the power output of a crystal controlled circuit. Condensers C_7 and C_8 in combination with the interelectrode capacities of the 50 watt tube form a capacity bridge circuit, which, when balanced, prevents self-oscillation of amplifier.

THE ALTERNATING CURRENT VACUUM TUBE TRANSMITTER

40. **VACUUM TUBE GENERATOR POWER SUPPLY.** One serious problem in the operation of power tubes is the high voltage plate supply, and the obtaining of the necessary voltage may be solved in several ways. The potential required varies with the size of the tube used. In the Navy, the plate voltage ranges from 350 volts for a tube of 5 watts output to 8000 volts for a tube with an output of 3 KW. Commercial direct current generators are designed to operate up to 3000 volts but when this voltage is greater than 500 volts the cost of low power machines becomes much higher than normal and they are subject to failure of the commutator and of the armature windings. In addition to these requirements direct current generators to be used in the plate circuit should have a constant voltage and be as free from ripples as possible. Removal of ripples is met by having as many commutator segments and armature slots as possible. Then again, high voltage generators require a large number of commutator segments for insulational purposes.

41. By using an alternator in the plate circuit of a vacuum tube, directly or inductively connected, the above difficulties met in the operation of high voltage direct current generators are avoided.

42. Commercial and governmental radio services are adopting alternating current plate supply for the above reasons and for spanning the gap between spark and CW transmitters and as a matter of economy because part of the power equipment ordinarily supplied for spark transmitters can be used and is already on hand. As much of the spark equipment as possible is employed.

43. **COMMERCIAL FREQUENCY POWER SUPPLY.** In the preceding explanations of the operations of the three element vacuum tube direct current power supply for both plate and filament has been shown or assumed. While the explanation of the action of the circuits is slightly simpler with direct current, there are various practical advantages which determine the use of alternating current for one or the other or both of the above mentioned circuits, in many cases.

44. Consider the circuit of Figure 9. Here is shown a simple vacuum tube circuit with a DC plate supply but with an AC filament supply. With the connections as shown a moment's consideration

will show that the power supply to the filament causes the "M" end of the filament to alternately become positive and negative with respect to the grid return. Stated the other way around, the potential of the grid with respect to the filament varies at the frequency of the e.m.f. supplied to the filament. This variation of e.m.f. with respect to the filament is different in magnitude for different portions of the filament. The "K" end of the filament to which the grid return is directly attached can have no variation of potential to grid caused by the AC filament supply. The difference of potential between the grid and the "M" end of the filament varies by an amount exactly equal to the filament voltage. Points of the filament intermediate between "K and M" vary by lesser amounts than this depending directly upon the distance from the end of the filament.

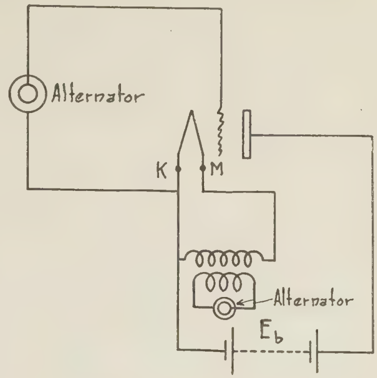


FIG. 9.—Vacuum Tube Circuit with Alternating Current Filament Supply.

45. Since the potential difference between grid and filament varies by an amount which on an average is equal to half the filament voltage, it is readily seen that this alone would be enough to cause a considerable variation in the plate current at the frequency of the filament power supplied. This variation is large enough to make the circuit shown useless for ordinary audio frequency use.

46. If the grid return could be connected to the center of the filament the potential of the grid with respect to one end of the filament would go up just as much as the potential with respect to the other end went down. Such a connection would of course require a specially constructed tube, so that it is not used.

47. A connection which is practically equivalent to connecting the grid return and plate circuit return to the center of the filament is shown in Figure 10. Here the point "O" is located midway between the two terminals of the filament. The two condensers C' and C'' of equal capacity serve to by-pass current variations around the resistances R' and R''. In this circuit the decrease of plate current flow to one portion of the filament is approximately counterbalanced by the increase of the flow to the other end portion of the filament. The accuracy with which this balancing occurs depends upon the straightness of the plate current grid voltage characteristic. If it were possible to confine the operation to a portion of the characteristic that had a constant slope the balance would be perfect and the operation of the circuit would be the same as with direct current filament. However, in practice, it is impossible to confine the operation of the tube to this portion of the characteristic curve.

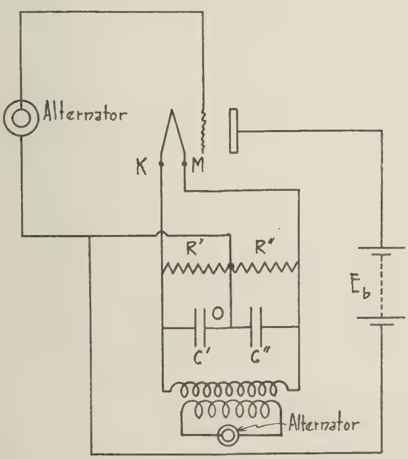


FIG. 10.—Vacuum Tube Circuit with Alternating Current Filament Supply.

Practically, no tube has a plate current characteristic which is straight over any appreciable range of grid voltage. The result of this is that the plate current variations in the two ends of the filament do not quite balance and a plate current variation at double the frequency of the filament power supply will be found. This may be small enough so that it is practical to use an AC filament supply even for audio frequency work in some circuits.

48. If a tube is being used in a circuit where the useful grid input and plate output are radio frequencies, an audio frequency variation in plate current is much less troublesome than in circuits handling audio frequencies. If the emission from the filament is ample to take care of both the incidental audio frequency variations and the useful radio frequency variations there is little difference in results due to the style of the filament heating used. Alternating current filament supply is frequently used for vacuum tube generators, for radio frequency generation.

49. In any vacuum tube generating circuit using direct current for filament heating and a direct current generator for plate power supply an alternating plate power supply may be substituted for the direct current with the result that intermittent operation will be obtained. Whenever the plate becomes sufficiently positive the circuit will generate. With negative voltages applied to the plate nothing happens in the generator circuit.

50. Figure 11 is a circuit of a vacuum tube generator using a direct current filament supply and an alternating current plate supply.

51. As connected, this circuit will generate oscillations only one half of the time. Now, since a heterodyne or self-heterodyne receiving system operates most efficiently when the generated wave is continuous, and further, continuous operation will produce lower maximum voltages for a certain transmitter power than half time operation, the desirable arrangement would be a circuit using two tubes employing an alternating current plate supply with either a direct current filament or alternating current filament. If two circuits each exactly similar to the one in Figure 11 were operated simultaneously from the same alternating current plate supply, but with the plate connections such that one plate is negative while the other is positive, one of these transmitters would transmit one half of the time while the other would transmit the other half.

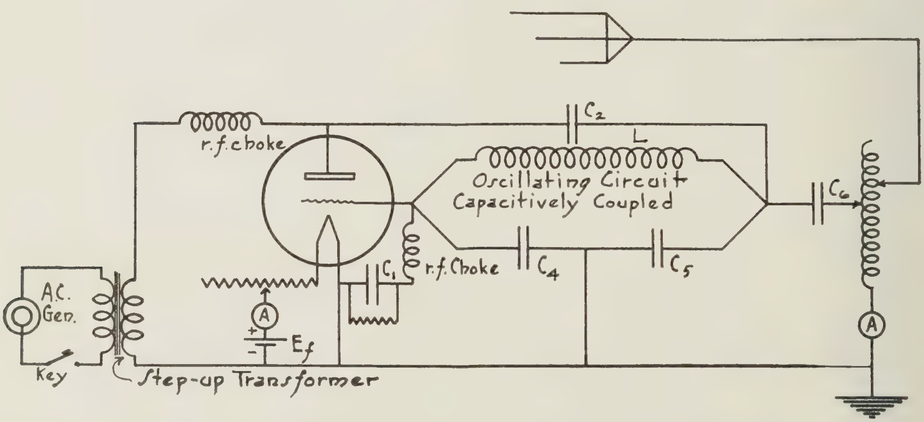


Fig. 11.—A.C.W. Generator Using One Tube and Direct Current Filament Supply.

52. By coupling both transmitters to one antenna as in Figure 12, continuous radio frequency current can be produced in the antenna which would fluctuate greatly in amplitude. As a matter of economy the duplicate parts which would be present and unnecessary if two complete transmitters were used have been eliminated.

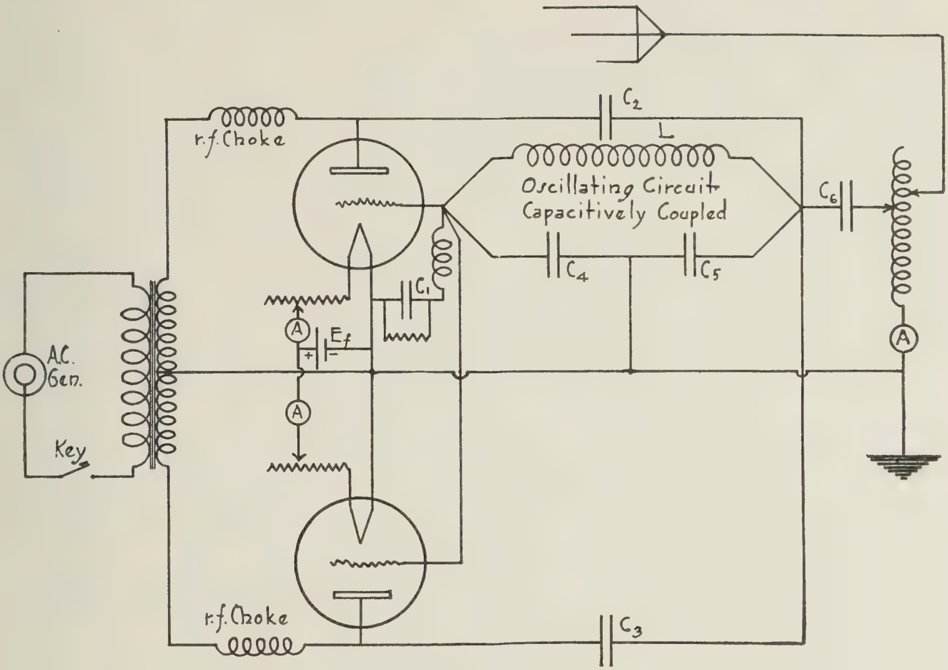


Fig. 12.—A.C.W. Generator, Using Two Tubes.

53. The interference caused by a V.T. transmitter using a certain power and a certain radio carrier frequency is decidedly greatei with A.C. plate supply than with pure D.C. plate supply. For this reason, it is probable that as money becomes available the Navy will put in D.C. plate supply where it now uses A.C.

CHAPTER XIV

THE RADIO TELEPHONE TRANSMITTER

1. **RADIO TELEPHONY.** Radio telephony is the reproduction at remote stations of sounds that are produced at the transmitting station, with radio frequency waves as the sound transmitting medium or carrier wave.

2. **SOUND.** A review of the paragraphs 14 to 19 inclusive in Chapter I will refresh the memory with the fact that all sources of sound are vibrating bodies capable of setting up vibrations in air or some material medium. Tuning forks are set into vibration by being struck, strings by being bowed, and instruments by the vibration of the reed, and in flutes and organ pipes the air itself in strong vibration sets up the vibration. These vibrations create sound by setting up in the air positions of compression of the molecules and positions of rarefactions of the molecules thus propagating through the medium a compressional or longitudinal wave whose velocity depends on the elasticity and density of the medium. When our ears receive this compressional wave we recognize the disturbance as sound. In order to hear sound it must have frequencies between 20 and 20,000 vibrations per second the exact limits of audibility depending upon the individual and the intensity of the sound. Sounds having frequencies between 500 and 1,000 cycles per second have a maximum effect on the ears for the same energy.

3. Abrupt and sudden sounds that do not last long enough to convey any idea of musical pitch, or mixtures of discordant sounds are **noises.** Sounds that have a sustained and simple character and do not seem to be a mixture of various different sounds may be called **tones** or **musical sounds.** Noises are generally disagreeable or irritating whereas tones are generally heard with pleasure or indifference.

4. A musical sound or tone possesses the physical properties of **pitch, intensity** and **quality.** The **pitch** denotes the frequency or the number of vibrations per second. Middle "C" on the piano for instance, has a frequency of 256, and any body vibrating at 256 cycles per second always has a pitch of C. The **intensity** or **loudness** represents the strength of the sound. The loudness is a function of the energy of the initial vibration and the distance the receiver is away from the source. Physically it means the energy transmitted through a square centimeter per second. The intensity is proportional to the square of the amplitude, the square of the frequency, the density of the medium and the velocity of vibration.

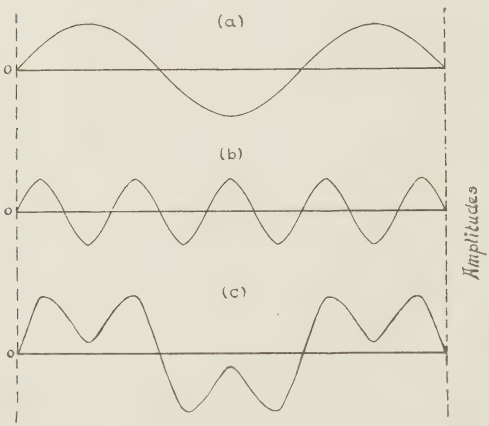


FIG. 1.—The Wave Form Resulting from the Composition of Two Simple Sine Waves.

5. By **tone quality** or timbre is meant that property by which we can tell the source of the sound, whether it is a tuning fork, a violin, an orchestra or a voice. The quality depends on the wave form of the sound, and this in turn depends on the number and intensity of overtones present.

6. In order to gain some idea of the complexity of sound assume that two tuning forks are vibrating and that the frequency of the second is three times that of the first and that the curves of each wave are simple sine waves, the three curves will be as indicated in Figure 1.

7. The curve representing the sound heard is obtained by adding algebraically the ordinates of the curves representing the waves transmitted by the tuning forks.

8. Amplifying this construction of sound it may be shown that nearly all sounds are composites. When any body is made to vibrate as a whole it sends forth the lowest tone of which it is capable, this being called the **fundamental tone.** If made to vibrate in several parts it sends forth also other tones which are called **overtones.** When, as is the case of most instruments, the overtone frequencies are exact multiples of the fundamental they are called harmonics. As the bell is nearly the only instrument whose overtones are not harmonics the two terms are usually used interchangeably. When a chord is played or struck as on a piano each note produces a fundamental and several harmonics. The ear analyzes this and is able to recognize the fundamentals which go to make up the chord.

9. **SPEECH.** Speech is composed of complex vibrations resulting in harmonics and overtones and a graphic record of the sound waves in air which transmits the simplest vowels shows a very complex wave form of varying amplitude.

10. Figure 2 (*a*) shows the wave form of a vowel sound. A study of this wave shows that its wave form is very complicated and that it repeats itself at regular intervals. Its frequency vibration is low or an audio frequency.

11. In wire telephony speech waves striking the diaphragm of a telephone transmitter vary the resistance of the circuit thereby varying the current in the circuit. When a telephone receiver directly or inductively connected is inserted in this circuit the changing currents will cause, through electromagnetic action, similar vibrations of the telephone diaphragm, thus reproducing the sound.

12. In radio telephony use is made of both the microphone transmitter and the telephone receiver in a similar manner to their use in wire telephony.

13. **REQUIREMENTS IN RADIO TELEPHONY.** In a radio telephone transmitter two requirements must be fulfilled, first, there must be provided a source of radio frequency energy, second, there must be provided means of modulating or controlling this radio frequency energy or current so that these variations of current will follow accurately the audio frequency variations of sounds to be transmitted in accordance with the method of transmission used.

14. **THE OSCILLATOR.** The source of the undamped oscillations may be the arc, the alternator or the three element vacuum tube. As only circuits employing the vacuum tube have been of any practical use, the discussion in this book will be limited to description of circuits using the vacuum tube.

15. The principal source of radio frequency energy is the vacuum tube which acts as a converter, changing the high voltage direct current to a radio frequency current.

16. As an oscillator in radio telephony is similar in operation to that of a continuous wave telegraph transmitter no further description will be given here since the latter has already been described.

17. **MODULATION OF THE RADIO FREQUENCY OUTPUT IN TELEPHONY.** The usual circuits in radio telephony utilize the strong dependence of radio frequency output current upon plate voltage for their successful operation. Thus, when the filament emission is large, the output current varies practically in proportion to the plate voltage.

18. In radio telephony, the amplitude of the radio frequency current in the antenna increases and decreases in accordance with the variations of current in the microphone.

19. Thus, if the vowel as represented by the curve in Figure 2 (*a*) is spoken into a microphone and starts at the point "Y" the variations in the microphone current will be represented as shown in Figure 2 (*b*). Before the moment "Y" the microphone current is steady.

20. The radio frequency oscillations which are to be transmitted will vary in amplitude as shown in Figure 2 (*c*) where the **"envelope"** of the oscillation shown by the dotted lines is the same form of curve as that in Figure 2 (*a*). The amplitude of these radio frequency waves is varied only while sound waves are striking the microphone.

21. These oscillations are radiated by the antenna, and when received by a suitable receiver, the current through the phones will duplicate the original microphone current thereby reproducing the original speech.

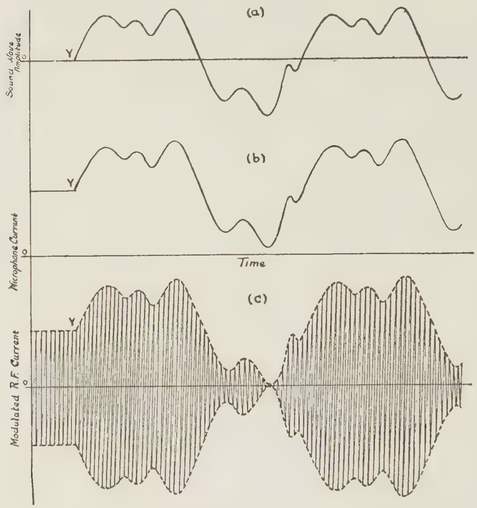


Fig. 2.—Radio Frequency Carrier Wave Modulated by Audio Frequency Sound Wave

22. **METHODS OF MODULATION.** In radio telephony two general methods of modulation are employed, in the first method the oscillator of the telephone system delivers a constant power output and the modulator action is applied directly to the antenna to vary the amplitude of the transmitted radio frequency oscillations; in the second, the modulator action is applied to the power supply to the transmitting system before the power has been changed to radio frequency.

23. These general methods of modulating the carrier waves can be more specifically classified as follows:

(a) Modulation by antenna control.
(b) Modulating the plate voltage of the oscillator tube.
(c) Modulating the grid voltage of the oscillator tube.

24. **MODULATION BY ANTENNA CONTROL.** The simplest method of modulation by antenna control is to connect a microphone directly or inductively to the antenna circuit. Voice waves striking the diaphragm of the microphone transmitter vary the resistance of the carbon granules which in turn modulates the radio frequency current in the antenna. This method of operation is limited owing to the small amount of power a microphone can handle.

25. **MODULATING THE PLATE VOLTAGE OF THE OSCILLATOR.** In the modulator-oscillator combination customarily used in radio telephone sets the microphone is transformer

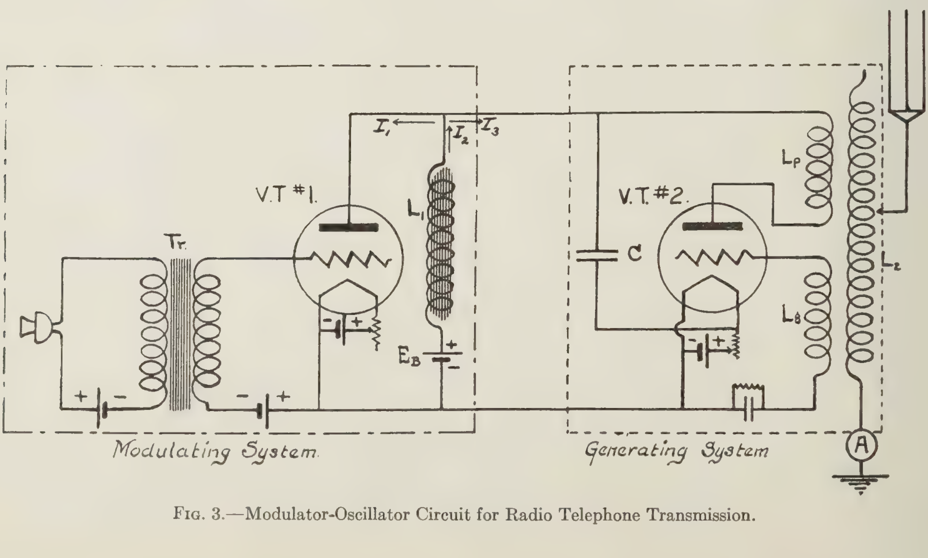


Fig. 3.—Modulator-Oscillator Circuit for Radio Telephone Transmission.

coupled to the grid circuit of the modulator tube, as in Figure 3, and varies the modulator grid voltage in accordance with the speech variations.

26. The operation of the modulator-oscillator system may be explained as follows: Voice or sound waves from a person speaking into a microphone impinge on the diaphragm of the microphone causing it to vibrate thereby varying the resistance of the circuit in which the microphone is inserted, thus causing a varying current to flow through the primary of the modulation transformer "Tr." The variations of current through the primary induces a similar voltage in the secondary. Due to the step-up ratio used, the secondary voltage is much greater than the primary. This secondary voltage (and that from the bias battery) is impressed upon the grid of the modulator tube, which in turn changes the current flow through the plate circuit of the modulator tube. In the plate circuit of the modulator tube is an audio frequency **choke coil** L_1 of high inductance and high reactance for oscillations of speech frequency. This coil operates the same as an auto transformer since it is in the plate circuit of both the modulator tube and of the oscillator tube. Both tubes have the same plate battery supply.

27. The important part of the system is the operation of the iron core **choke coil** L_1 and its action on the current supplied to the plate circuits of VT_1 and VT_2 by the plate supply battery "E_B." The name choke is applied to an electrical device which tends to eliminate or choke down **variations** in current passing through it, or in this case a device which tends to maintain an unvarying current from the high voltage battery "E_B," no matter what the controlling action of the grids of the two tubes may be. Thus, if the modulator tube VT_1 and oscillator tube VT_2 divide the supply current equally when no speech is present, a change in modulator grid voltage which causes three-fourths of the plate current to go to the modulator should cause only one-fourth of the original current to go to the oscillator. Similarly, any **variation** in current through the modulator VT_1 will cause a **change** in the current through the oscillator VT_2 which in turn directly affects the strength of the current in the antenna circuit.

28. Keeping in mind the action of the choke coil to maintain an unvarying current from the plate supply voltage, we should note that the voltage across the secondary of the transformer "Tr." resulting from the changing of the resistance of the microphone when impressed on the grid of the modulator VT_1, will affect the current flow between the plate and filament of this tube, which in turn affects the current from the plate to filament of the oscillator VT_2, thus controlling the output of the oscillator.

29. To further explain this action let us presume that at a certain time the voltage impressed between the grid and the filament of VT_1 is $E_g = -20$ volts and that the modulator plate current is equal to the oscillator plate current. Now, if this modulator grid voltage is changed to $E_g = -30$ volts, the modulator plate current will decrease thus causing an increase in the oscillator plate current and voltage and output thus resulting in increase in amplitude of antenna current. A similar change to $E_g = -10$ volts would cause the modulator plate current to increase thus causing a decrease in oscillator plate current and voltage and output, thus controlling the amplitude or strength of the radio frequency current in the antenna system.

30. In order that the best results may be obtained the amplitude of the radio frequency oscillations for speech of moderate intensity should have a maximum variation from zero to double the amplitude corresponding to no speech. An alternating current is said to be modulated when the amplitude of its oscillations is varied periodically. It is said to be completely modulated when the amplitude of its oscillations is reduced periodically to zero. Figure 2 (c) is an example of complete modulation.

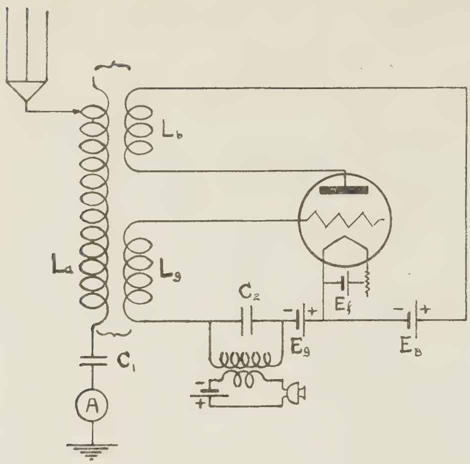


Fig. 4.—Microphone in Grid Circuit.

31. **MODULATING THE GRID VOLTAGE OF THE OSCILLATOR.** In this method of modulation the secondary terminals of the transformer in a microphone circuit are connected to the grid connections of the oscillator tube. Figure 4 is a circuit employing this method of modulation in a Meissner circuit. This method of operation is not very effective since the amplitude of the oscillations generated by a tube does not depend strongly upon the grid voltage. If the grid voltage is reduced below the range of stable operation the vacuum tube may cease to operate. It is obvious, therefore, that this is a poor method of modulation.

32. **SPEECH AMPLIFIER.** Except in the smallest sets, the output from the microphone circuit is not sufficient to vary the modulator grid voltage enough to modulate the output efficiently. This difficulty is overcome by using one or more vacuum tubes as audio frequency amplifiers between the microphone and the modulator grid. Such an audio frequency amplifier is known as a "Speech amplifier."

33. **BUZZER MODULATION.** Modulation produced by substituting a buzzer and key for the microphone is known as "buzzer modulation." This form of modulation is sometimes used in the Navy on combination telegraph and telephone transmitters. It is not considered as satisfactory as the A.C. plate supply V.T. transmitter.

CHAPTER XV

ANTENNAS

1. **DESCRIPTION OF ANTENNAS.** In radio communication devices that are used to radiate electric waves or to receive electric waves are called antennas. There are two general classes of antennas, those which act primarily as electrical condensers and those which act primarily as electrical inductances. The first type which will be discussed in this chapter, is referred to simply

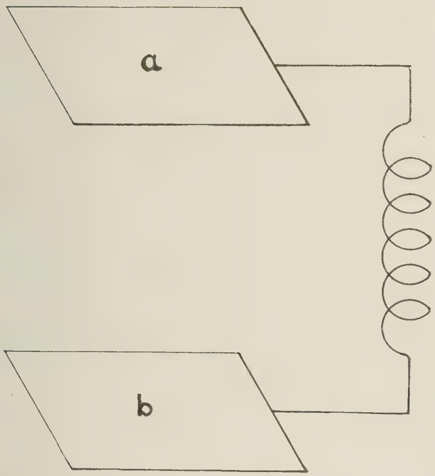


Fig 1.—Simplest Form of Antenna.

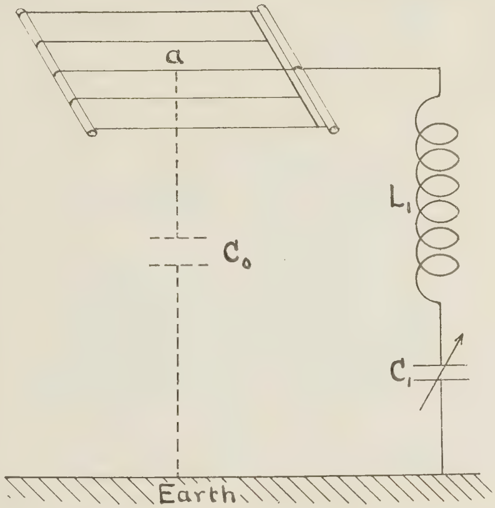


Fig. 2.—Practical Form of Antenna.

as an "antenna" and the second type, which will be discussed in Chapter XVI, as "coil antennas," "loop" or "direction finder" depending on use.

2. An antenna in its simplest form is shown in Fig. 1. It consists of two plates "a" and "b" separated by a dielectric, thus forming a condenser.

3. A practical form of antenna circuit is shown in Fig. 2, the earth being substituted for the lower plate. The dielectric is the air between the earth and the antenna wires.

4. The upper plate is designated usually as the antenna and the lower plate as the counterpoise. The earth acts as the counterpoise in the fundamental antenna circuit of Fig. 2. In this circuit the condenser C_0 indicates the capacity effect between the antenna and the ground. The antenna system may be inductively coupled to either a supply or receiving circuit by means of the inductance L_1. The inductance may be variable as shown and the total capacity of the circuit may be varied through small limits below the maximum C_0 by means of the variable condenser C_1.

5. There are two general subdivisions of the types operating as condensers, the elevated antenna and the aircraft antenna. Examples of the elevated antenna are the "T," Inverted "L," "Umbrella," and "Cage," see Figures 3, 4, 5, and 6, respectively. Aircraft antenna of the condenser type are trailing wire, kite, and skid-fin.

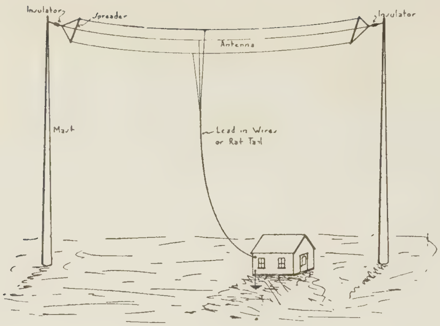


Fig. 3.—"T." Antenna.

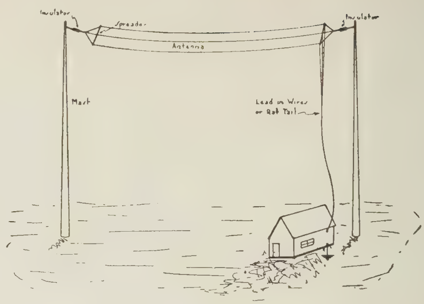


Fig. 4.—Inverted "L" Antenna.

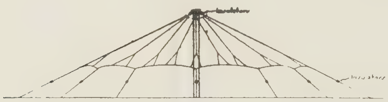


Fig. 5.—Umbrella Antenna.

Fig. 6.—Cage Antenna.

6. The "T," Inverted "L" and "Cage" types are used aboard ships; the "Umbrella" type is used for portable sets and has been used for some shore stations. The "T" and Inverted "L" varieties are further known as "flat topped" antennas.

7. The "trailing wire" antenna consists of a single wire carried on a reel that is mounted in either the boat or the fuselage as shown in Fig. 7.

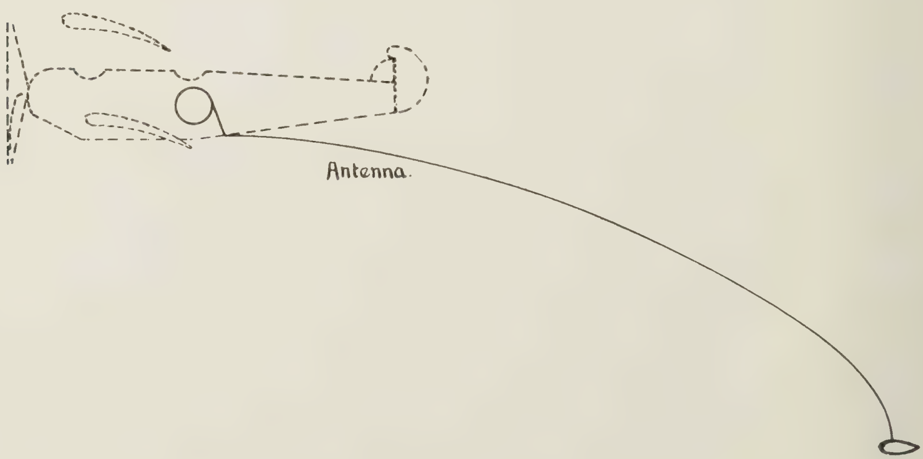


Fig. 7.—Trailing Wire Type of Antenna.

8. Fig. 7 shows the trailing wire antenna in the approximate form in which it would hang down from the fuselage of an aircraft when in the air. From this it can be seen that even with the large weight on the end of the wire the antenna does not hang far below the craft.

9. The "Skid-fin" antenna for large heavier-than-air craft is not as efficient as the trailing wire type for intermediate or low radio frequencies. It may be quite efficient for frequencies of the order of 7500 kcs. (or higher). It has one very decided operating advantage in that it can be used at times when the aircraft is not in the air. Plan and front elevation of a skid-fin antenna are shown in Figure 8.

10. **ADVANTAGES OF DIFFERENT TYPES.** The umbrella type is not employed except as noted above. It has the advantage, for shore stations, of requiring but one supporting mast, the

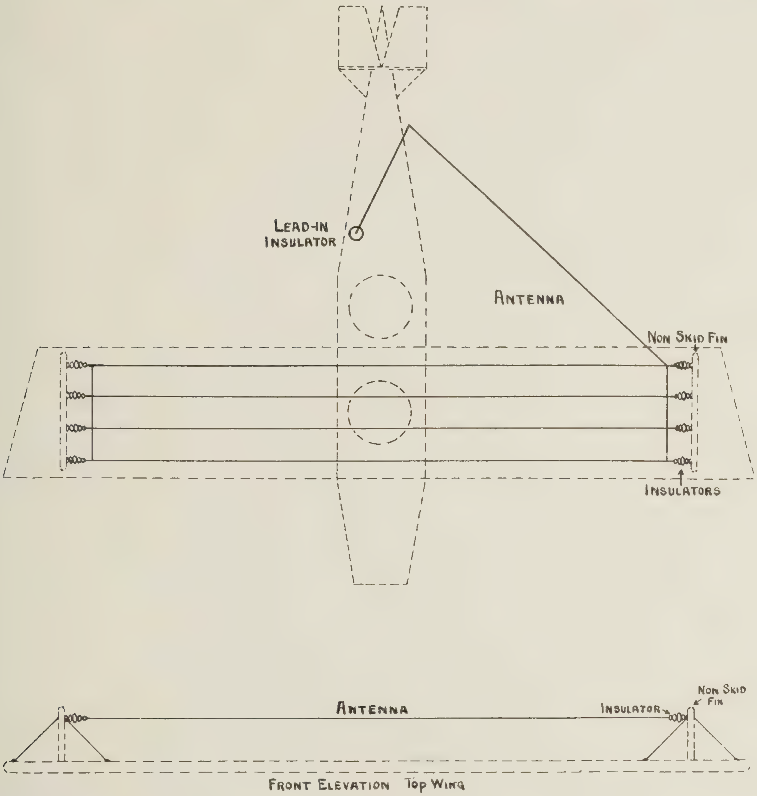


Fig. 8.—Skid-fin Type of Antenna. Plan View and Front Elevation of Top Wing Showing Antenna Connections

antenna wires themselves serving as guys. The "T" and Inverted "L" types are well adapted to use aboard ship where two masts are usually available. In large shore stations, however, these types require four or sometimes as many as six masts or towers for support. The Annapolis High Power station has six 600 ft. towers, Pearl Harbor has four.

11. For equal lengths of wire the "T" type has a shorter natural wave length than the Inverted "L" type. Therefore the "T" type will require larger inductances than the Inverted "L" type for the same frequency. The Inverted "L" type has some "directional characteristic"; it receives best from the direction opposite the open end. The "cage" type takes less clear space for support than a flat top antenna. It consists usually of 6 or 8 parallel wires equally spaced around a circular spreader, thus making the complete antenna cylindrical in form. For military purposes it has the advantage of being serviceable even if two or three wires are shot away.

12. **THE CAPACITY OF ANTENNAS.** A single wire may serve as an antenna. Increasing the number of wires increases the capacity but not in direct ratio; thus, doubling the number of wires does not double the capacity. Increasing the length of a wire increases its capacity.

13. It is desirable to have as large a capacity as possible in an antenna, since the larger the capacity the less the voltage required for the same charge. This is apparent from the formula, Q (coulombs) = C (farads) $\times E$ (volts).

14. The less the induced voltage the less the leakage and losses due to brush discharge and the better the antenna may be insulated from its supports.

15. The capacities in **microfarads** of the ordinary types of antennas which may be encountered in practice are as follows:

Airplane and small amateur stations	0.0002-0.0005
Ship stations	0.0007-0.0015
Large shore stations	0.0050-0.0150

Notice that these values are of the same order as the capacities found in ordinary variable air condensers and yet an expensive antenna system and a supporting structure are necessary to radiate or absorb the electromagnetic waves properly.

16. **INDUCTANCE OF AN ANTENNA.** It was pointed out in a previous chapter that a plain straight wire has distributed inductance. Therefore, an antenna also has distributed inductance and this increases with the length of the antenna.

17. **THE NATURAL FREQUENCY OF AN ANTENNA** depends then on its natural distributed capacity and its natural distributed inductance without the addition of either capacity or inductance in a concentrated form either as condensers or as coils respectively.

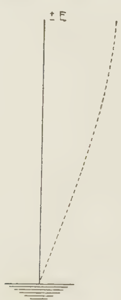


FIG. 9.—Voltage Distribution in Vertical Antenna.

18. **VOLTAGE DISTRIBUTION IN A SINGLE VERTICAL WIRE ANTENNA.** This is shown in Fig. 9. The grounded end must be at ground potential or zero. And since the antenna current is not evenly distributed the voltage will not vary uniformly from ground to the open end. At the open end the voltage oscillates at a maximum on either side of the ground potential. Therefore the open end of an antenna requires especially good insulation.

19. Fig. 10 shows the same antenna tuned to a frequency **less** than its natural frequency with an inductance (loading) coil in series with the antenna.

20. Fig. 11 shows the effect when a series condenser is used to tune to a frequency **higher** than the natural or fundamental frequency of the antenna. The condenser reverses the sign of the antenna charge and a low potential point is formed part way up the antenna.

21. **CURRENT DISTRIBUTION IN A SINGLE VERTICAL WIRE ANTENNA.** Fig. 12 shows an antenna divided into five equal parts. The distributed capacity effect to ground at the middle of each part is indicated by a condenser. Since the lowest section of the wire is nearest to the ground, the thickness of the dielectric (air) is the least. Hence the capacity is the largest for this section. So on up the antenna, the capacity effect diminishes, C_5 being the smallest. Therefore, the current through C_1 is largest, and through C_5 the smallest. The current distribution is then as shown in Fig. 13, which is a quarter of a cycle later than that of the voltage in Fig. 9. When the voltage is zero, the current is a maximum. Figs. 12 and 13 show that receiving apparatus should be placed as near the ground connection as possible in order to take advantage of the large current in the lowest part of the antenna system. The following points are pertinent: (a) A large proportion of the antenna current flows through the capacity in the lowest parts. (b) It is important to have a conductor of as low a resistance as possible in the lowest part of the antenna system. (c) The reading of the antenna ammeter may be very misleading if the lowest parts of the antenna system are run carelessly so as to have large capacity effect to ground. (d) The energy distribution around a symmetrical antenna is fairly symmetrical since where the voltage is high the current is low.

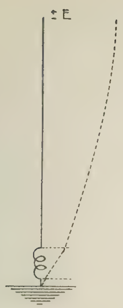


FIG. 10.—Voltage Distribution with Inductance Coil in Vertical Antenna.

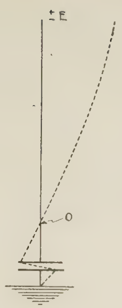


FIG. 11.—Voltage Distribution with Condenser in Vertical Antenna.

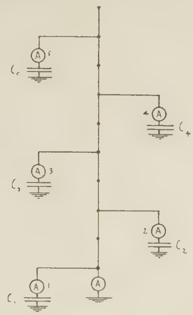


FIG. 12.—Distributed Capacity Effect in Vertical Antenna.

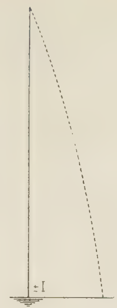


FIG. 13.—Current Distribution in Vertical Antenna.

22. **ANTENNA GROUND CONNECTION.** A good ground connection reduces the possible value of the effective resistance of the antenna system. The resistance affects not only the maximum value of the current oscillations but the damping as well.

23. Moist earth gives the best ground connection. The connection is made usually with large metal plates buried in the moist soil. These plates should be made of non-corrosive material since rust scale is a poor conductor. The leads to and between plates should be well and heavily soldered.

24. In large antenna systems heavy plates are used, being distributed over the projected area of the antenna proper. In some cases a network of buried insulated wires may be substituted for the plates.

25. On a ship with steel hull there is no difficulty in securing a good ground connection. It should be made to the hull itself, below the waterline and to the clean bare metal. Paint is a good insulator and must be scraped off. The ground wire should be soldered or oxy-acetylene welded to the hull plating. Solid metallic contact is required.

26. On a ship with copper sheathing the ground connection may be led over the side and secured to the sheathing at a place where there is the least possibility of the connection being broken or torn away.

27. On a ship with a wooden hull only it is necessary to lead the ground connection to a metal plate on the outside of the hull and sufficiently far below the water line to allow for change in draft and heaviest rolling. The location should provide proper protection. If such a ship is a sailing vessel with auxiliary engine or a steamship, a good connection may be made to the stern tube in the shaft alley. Thus the connection is inside the ship and protection is the best. In the case of ships the rest of the ground connection is through the surrounding water.

28. **A COUNTERPOISE.** When the land of a shore station is of rocky nature or is dry and a good ground connection is impossible by any of the means described in preceding paragraphs, resort is had to what is called a "counterpoise," shown in Fig. 10. The counterpoise replaces the earth as one plate of the condenser of which the antenna proper is the upper plate. A counterpoise usually takes the form of the antenna and is directly below and parallel to the latter and insulated from the ground. See Chap. XVIII par. 30 for aircraft counterpoise.

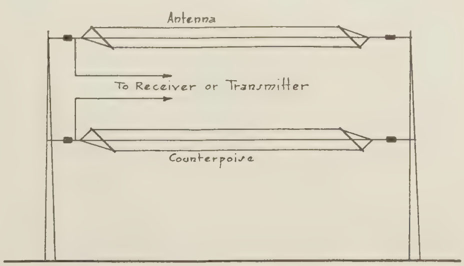


FIG. 14.—Antenna and Counterpoise.

29. **HEIGHT OF ANTENNA.** As a general principle, the higher the antenna the better it transmits and receives. On large shore stations

the height of the antenna is limited by the power to be radiated as well as by the cost of the antenna towers or masts. On board ship the masts limit the maximum height to about 135 ft. above the waterline.

30. **THE POWER DISSIPATED BY AN ANTENNA.** The total power is dissipated in the following ways: (a) As heat in the antenna wires and in the earth connection. (b) As brush discharge. (c) As leakage over or through insulators. (d) As heat in the dielectric surrounding the antenna, and in any condensers that are in the antenna circuit. (e) As radiated waves. Part of (e) will be turned into useless heat also by inducing eddy currents in nearby conductors such as guy wires or metal masts.

31. To reduce dielectric losses, no portion of the antenna should be near buildings or trees. Wooden stakes, bushes, brush, trees, or structures under a counterpoise will cause a dielectric loss.

32. To reduce eddy losses, the antenna should be as far as possible from guy wires, iron smoke stacks, or masses of metal. Guys should be rigged in sections insulated from one another. Any nearby stays should be sectioned also to prevent their having a natural frequency corresponding to that of the antenna.

33. Brush discharge is noticeable at night as a silent bluish glow at or near the top of the antenna where the voltage is the highest, and in the direction of the nearest grounded object.

34. Leakage may take place over the surface or through the body of an insulator. It may be due to a poor insulator, or to an accumulation of dirt, soot, or moisture. Salt spray increases the leakage.

35. **RADIATED WAVES.** These are part of the power dissipated by an antenna but do not represent a loss since it is desired to radiate as much power as possible. These waves suffer some loss, by absorption, in travelling over the earth's surface. High frequency waves are affected more adversely than low frequency waves, especially over long distances.

36. **INSULATION OF AN ANTENNA.** The antenna must be insulated from its supports. The supports should be insulated from ground if construction permits. Pyrex makes the best practical insulator. Such an insulator should be homogeneous throughout and have sufficient mechanical strength under tension. Its surface should be well glazed, smooth, and present as long a path as possible to reduce leakage over the surface. A type of antenna insulator is shown in Fig. 15. The insulator must be sufficiently long to prevent the voltage from jumping directly across its length. A type of porcelain insulator called a strain insulator used between sections of guys is illustrated in Fig. 16. If the insulator is crushed, the guy is not parted since the eyes are interlocked. As already mentioned the ends of an antenna should be particularly well insulated since the highest voltage exists at the end of the flat top.

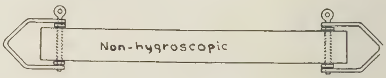


Fig. 15.—Antenna Insulator.

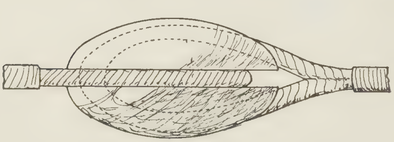


Fig. 16.—Strain Insulator.

37. **INSULATORS.** Insulators should be kept **clean.** Accumulation of dirt, soot and moisture (especially fine salt spray) reduces the effectiveness of an insulator as such. The lead-in wires to receiving set should be well insulated.

38. **WIRE USED FOR ANTENNAS.** Hard drawn copper is satisfactory if not subject to kinks which reduce its tensile strength. Phospher bronze wire is stronger than copper but corrodes more. It is also expensive and has a higher ohmic resistance than copper. Aluminum is light but has not a very great tensile strength. It is cheaper than copper, but for equal areas and same lengths has slightly higher resistance than the copper. Also special attention must be given to connections.

39. To reduce the skin effect, antenna wire is made up of several strands woven or braided together. Also such a wire is flexible, easily handled and not subject to kinking. The strands are usually enameled. However, the resistance may be greater than that of a single equivalent solid conductor. A weathered conductor may have higher resistance than a new one. Iron or steel wire has too high an ohmic resistance. When heavily galvanized they may be used since the current

travels in the coating. Iron and steel wires coated with copper have been used for antennas, most of the current flowing in the copper, the ohmic resistance of the iron or steel having very little effect. Enamel is used on antenna conductors to prevent or at least reduce the action of weather, smoke, acid fumes, or other corroding agencies.

40. **ANTENNA SWITCH.** A switch is always provided for connecting the antenna to ground when not in use, as protection from lightning. This same switch is used to connect to the receiving circuit and the transmitter as well. It is so arranged that the receiving circuit can not be connected to transmitter. Amateurs are required, by the underwriters, to have a lightning protection in the antenna circuit outside the building. Lightning arresters are used in large installations also.

41. **ANTENNA RESISTANCE.** The "effective" resistance of an antenna is greater than the ohmic resistance, due to skin effect at high frequencies. The radiation of energy in waves further increases the apparent resistance of an antenna. The "effective" resistance of an antenna is defined

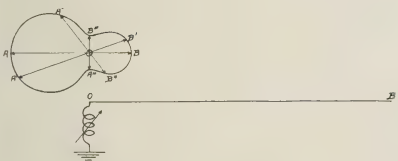


Fig. 18.—Directional Characteristic of Inverted L Antenna.

Fig. 17.—Directional Characteristic of Vertical Antenna. A

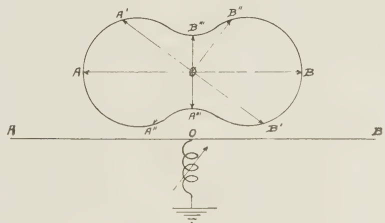


Fig. 19.—Directional Characteristic of T Antenna.

as the quotient of the power given to the antenna by the square of the antenna current. If R is the effective resistance and I the current measured at the lower end of the antenna, the power is I^2R. R changes with the frequency.

42. **GROUND ANTENNA.** With the introduction of the V.T. it was found that signals could be received by means of a wire laid on the ground. Such a wire is called a "ground" antenna. This wire may be buried in the ground. It must, however, always be insulated from the ground. In military operations it may be laid out or taken up quickly. A ground antenna requires sensitive receiving apparatus.

43. **DIRECTIONAL CHARACTERISTICS OF AN ELEVATED ANTENNA.** The vertical wire antenna, Figure 17, transmits electrical waves equally well in all horizontal directions. This fact may be ascertained by transmitting a signal and having an observer equipped with a receiving instrument move around the antenna in such a direction as to keep his instrument reading the same value. If this distance from the antenna is measured at the start, he will find that his path was the circumference of a circle with the antenna as the center of the circle (see plan view Figure 17.). In a similar test of the long low top Inverted "L" antenna of Figure 18 (length of top five or more times the height), the plan view shows that its energy is radiated with greatest intensity in the direction of its grounded end or the end opposite to the free end. The length of a radius vector of the polar diagram in Figure 18 shows the relative strength of transmitted signals for various values of the angles at the transmitting station between horizontal antenna length and the receiving station. When the vertical height and the length of the flat top are equal the directional characteristics are not very pronounced. The "T" antenna may be considered as two Inverted "L" an-

tennas. The plan view of the "T" antenna of Figure 19 shows that it transmits equally well from the open ends but not to the same extent in other directions. The directional characteristics of a receiving antenna are the same as those of a similar transmitting antenna.

44. **DIRECTIONAL CHARACTERISTICS OF AIRCRAFT ANTENNA.** Any trailing wire antenna that does not hang straight down from the aircraft has a certain amount of directional characteristics. It is often noticed by radio operators in seaplanes that where two planes are flying parallel within a short distance from each other that it is practically impossible for the two planes to carry on radio communication. This is owing to the fact that an antenna that is bent does not either receive or radiate efficiently in the direction of the axis at right angles to the radius of the bend. An extreme case of this is in the application of the rectangular loop to the radio compass. In this case there is a wide range between the strength of signals received when the direction of the signal is parallel to the axis of the coil and when it is at right angles to the coil.

CHAPTER XVI

COIL ANTENNAS

1. It has been explained in a previous chapter how an approaching radio wave induces an e.m.f. in the ordinary elevated type of antenna. We can consider the action of this type of antenna as that of an electrical condenser.

2. It is also possible to use a type of antenna which acts primarily as an electrical inductance. This type is ordinarily called a **coil** or **loop antenna** and consists as its name suggests of one or more turns of wire forming a simple inductance. The usual type is illustrated in Figure 1.

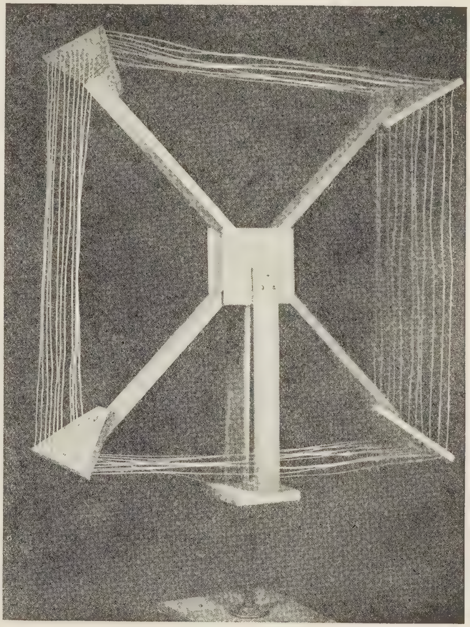


FIG. 1.—Usual Type of Coil Antenna.

3. Coil antennas are particularly used where a compact portable type of antenna is desired or when an antenna having a marked directional characteristic is desired.

4. It cannot be emphasized too strongly that satisfactory results cannot be expected in reception using coil antennas unless very good electron tube amplifiers are used to amplify many times the feeble current received in the coil. Usually a six-stage amplifier is used for satisfactory results.

5. Coil antennas may be used for either transmission or reception, but their use for transmission is rather limited while their use for reception is extensive and constantly increasing.

6. **ACTION OF COIL ANTENNA.** The action of the coil antenna can be considered from different points of view. We can imagine two vertical wires of the same length, say 300 meters apart, supported by and insulated from any convenient supports, with their lower ends also insulated. Then any radio wave approaching the two wires will induce an electromotive force in each wire If the wave approaches from a direction perpendicular to the plane of the two wires, the crest of the wave will reach each of the wires at the same instant, and the two induced electromotive forces will be of exactly the same magnitude and tend to cause equal currents to flow in the same direction in the lower ends of both wires. This condition is shown in Figure 2(a). Now if the tops of these wires are connected as shown in Figure 2(b), the two induced voltages are acting in opposition; that is, they are 180° out of phase and no current can flow from the loop to an external circuit such as a receiving set. If we assume a wave approaching from the direction of the plane of the wires having a wave length of 600 meters, the electromotive forces induced in the lower ends of the two wires will then be in the directions shown in Figure 2(c), E_1 being a maximum downward at the same instant that E_2 is a maximum upward. A conductor connecting the two wires as shown in Figure 2(d) then causes the two voltages to act together around the loop; that is, the voltages are in phase. A receiving set can detect this radio frequency current in the usual manner.

7. In practice, the coils cannot be made as large as the one used in this explanation, the ordinary loop antenna being at most only a few meters across. In this case, the operation of the loop when the wave approaches from a direction perpendicular to the plane of the wires is the same as shown in Figures 2, (a) and (b); when the wave approaches in the direction of the plane of the wires the two induced electromotive forces are only a slight angle from opposition (180° out of phase), this angle depending on the length of the incoming wave and the distance from one side of the coil to the other. The horizontal wires contribute nothing to the effective electromotive force induced in the coil circuit. The induced electromotive forces in a coil therefore go from a minimum when the plane of the coil is perpendicular to the direction of the incoming wave to a maximum when the plane of the coil is in line with the direction of the incoming wave, intermediate positions giving intermediate amplitudes of received signal. Assuming a loop with three meters between the conductors on each side and a 600 meter incoming wave, the maximum signal would be heard when

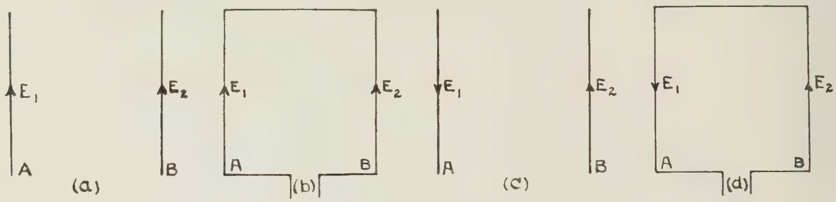


FIG. 2.—Electromotive Force Induced in a Loop.

the phase difference of the two induced voltages $= \frac{3}{300} \times 180° = 1.8°$ from 180° opposition, 300 being one-half wave length. The induced electromotive forces in this example would be 178.2° out of phase.

8. For a wave approaching from a direction perpendicular to the plane of the two coils, the e.m.f.'s induced in the two vertical wires will be exactly 180° out of phase, and the e.m.f. at the lower end of one vertical wire will reach a maximum at the same instant as the e.m.f. at the lower end of the other vertical wire, and no current will flow in the rectangular circuit.

9. A similar explanation will obtain for a wave length other than twice the distance between the two vertical wires provided the distance between them is not more than half a wave length. For a given wave length, the maximum instantaneous potential difference will exist across the lower ends of the two wires for a wave approaching in the direction of the plane of the two wires, and no potential difference will exist for a wave approaching perpendicular to this direction.

10. The rectangular circuit consisting of the two vertical wires and the two horizontal cross connections constitutes a **Coil Antenna.** Another way of regarding the action of the coil antenna is to consider it as an inductance coil which is threaded by the magnetic field of varying intensity which is associated with a radio wave. As pointed out in paragraphs 13 and 14, Chapter VII, this varying magnetic field is at right angles to the direction of travel of the wave and is horizontal. When the wave is traveling in a direction perpendicular to the plane of the coil, no lines of magnetic force are linked with the coil and no resultant electromotive force is induced in the coil.

11. It is obvious that if the coil is mounted on a frame which can be rotated about a vertical axis, then for a wave approaching from a given direction the position of the coil can be adjusted so that zero signal or maximum signal may be obtained in receiving apparatus connected to the coil circuit.

12. In both the elevated and coil types of antennas an approaching radio wave induces an e.m.f. in a wire or arrangement of wires. In the ordinary elevated antenna the induced e.m.f. causes a current to flow in a circuit which includes a condenser consisting of the antenna and ground, or antenna and counterpoise. In the coil antenna the induced e.m.f. causes a current to flow in a completely metallic circuit connected to the detecting apparatus.

13. **COIL ANTENNA CIRCUIT.** A simple coil antenna receiving circuit is shown in Fig. 3. The coil is tuned to the frequency of the incoming wave by means of a variable condenser connected across its terminals. These terminals are also directly connected to the grid circuit of the vacuum tube amplifier.

14. **RADIO COMPASS.** If a coil antenna is mounted on a vertical axis so that it can be rotated freely, and a curve is plotted showing for a wave approaching from a particular direction, the variations in the strength of the received current as the coil is rotated, there will be obtained the same kind of a curve as the polar coördinate one shown in Fig. 4. A coil so mounted is called a **Direction Finder** or **Radio Compass.**

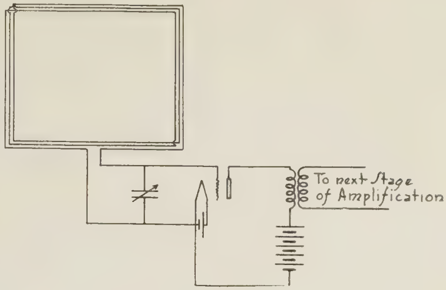


Fig. 3.—Coil Antenna Receiving Circuit.

15. **CHARACTERISTIC OF RADIO COMPASS.** By rotating the coil while receiving from a particular station it is possible to locate the line of direction of the station. The coil may be oriented for maximum signal in which case the transmitting station lies in the plane of the coil; or the coil may be set for minimum signal in which case the transmitting station then lies in a direction perpendicular to the plane of the coil. It will be noticed by reference to Fig. 4 however, that for a variation of say 3 degrees, a much greater change in received current is caused when the coil is at the minimum signal strength than when at the maximum. Therefore a much more accurate determination of minimum position is possible than of maximum, and the minimum method is the one usually used for direction finder work. One difficulty with the minimum method is that the minimum signal may be obscured by transmission from another station. The maximum method is not subject to this objection.

16. A direction finder is provided with a horizontal graduated circle to identify the position of the plane of the coil. To make a determination of direction the coil is rotated on its vertical axis until the signals disappear. Referring to Fig. 4, the positions C and D are then noted for which the signals just disappear and just become audible respectively, and then the coil is turned 180° and the two similar positions E and F are found. By taking the average of the circle readings at C and D, and at E and F, that position of the coil may be determined which lies at right angles to the direction from which the signal is arriving.

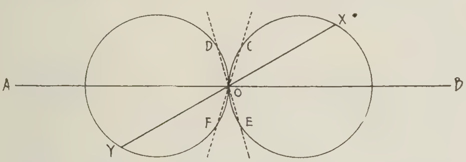


Fig. 4.—Directional Characteristic for Radio Compass with Balancing Condenser.

17. The characteristic shown in Fig. 4 consisting of two equal tangent circles is an ideal characteristic and fails to take into account several conditions found in practice.

18. As has been stated, a coil antenna can be considered to act primarily as an inductance. It is, however, an arrangement of wires elevated above the ground, and with the ground forms a condenser. The coil antenna will act as an ordinary condenser antenna to an extent depending on what kind of a condenser it forms with the ground. In considering this condenser we should take into account not simply the capacity of the coil alone to ground, but also the capacity of all the receiving apparatus associated with the coil.

19. Let us return to the consideration of the coil antenna as two ungrounded simple vertical wire antennas having the same length as the height of the coil. The e.m.f. induced by an approaching wave in each wire will tend to cause a current to flow between each vertical wire and the ground through the capacity of each vertical wire to the ground. If the coil system is symmetrical about

its vertical axis, and the receiving apparatus associated with the coil is symmetrical with respect to this axis so that the capacity to ground of each lateral half of the coil and coil circuit is the same this effect is not important and will not destroy the symmetry of the directional characteristic.

20. In the circuit shown in Fig. 3 it will be noted that the filament battery and other apparatus is connected to the left terminal of the coil, while the right terminal of the coil is connected only to the grid of the first tube. The filament battery of course has an appreciable capacity of its own to ground and therefore the system consisting of the coil and its associated apparatus has a greater capacity to ground on the side to which the filament connection is made than on the other side. Other parts of the circuit and the operator's body may also contribute to unsymmetrical capacities to ground. The e.m.f.'s induced in the two vertical sides of the coil will cause a current to flow through the unsymmetrical ground capacities, and this current will flow even when the coil is perpendicular to the direction in which the wave is traveling.

21. The effect of the above is that the directional characteristic of a coil system with unsymmetrical capacities to ground is not the two equal tangent circles shown in Fig. 4, but is a figure shaped like an hour glass, the width of the neck depending on the extent to which the capacities are unsymmetrical. There is an appreciable signal when the coil is at right angles to the direction of the approaching wave, and if an effort is made to rotate the coil to determine this direction it is much more difficult to determine the position of minimum signal.

22. **BALANCING CONDENSER.** This troublesome effect can be **reduced** by placing the batteries as far above the ground as is practicable. It can be **eliminated** by the use of a **balancing (compensating) condenser** connected as shown in Fig. 5. This is simply a variable condenser connected between the grid and the ground so that the capacity of the grid to the ground may be varied. It is adjusted until the capacity to ground on the side of the coil connected to the grid is equal to the capacity to ground on the side connected to the filament. This restores the sharpness of the position of minimum signal. Compensation is is not particularly important when a coil antenna is being used simply for **reception,** but is very important when it is being used for **direction finder work.**

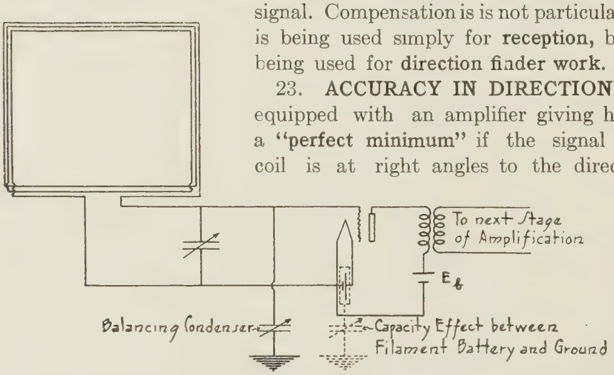


Fig. 5.—Coil Antenna Receiving Circuit with Balancing Condenser.

23. **ACCURACY IN DIRECTION FINDING.** A direction finder equipped with an amplifier giving high amplification is said to have a **"perfect minimum"** if the signal entirely disappears when the coil is at right angles to the direction of the approaching wave. This perfect minimum can be obtained only with very good balancing. It is evidently desirable to have a very sharp minimum both to obtain accurate settings and to obtain speed in taking bearings. In order to get a sharp minimum it is necessary to have a fairly strong signal and a good amplifier, usually a six-stage one. Under such conditions an experienced operator can often make a very accurate setting with only two swings of the coil.

24. **ELIMINATION OF INTERFERENCE.** In paragraph 31 of Chapter VII reference was made to strays or other atmospheric disturbances which often cause serious interference in radio reception. Strays of some kinds come from particular directions and can be minimized by directional reception that is the ratio of signals to strays is increased by directional reception. Coil antennas are often used for this purpose.

25. Directional reception can also be used for eliminating signals from stations which it is not desired to receive. For long distance reception, coil antennas are largely used now. The coil antennas used may be out of doors and of dimensions comparable to those of an ordinary antenna of medium size.

26. **UNIDIRECTIONAL DIRECTION FINDER.** The simple coil antenna having a symmetrical characteristic will give the line of direction of a transmitting station but will not tell on which side of the observer the transmitting station lies. It is evident that if we have an antenna having an unsymmetrical directional characteristic such as that of Fig. 18, Chapter XV, it will also be possible to tell on which side the transmitting station lies. In general it is found that the **line of direction** can be determined more accurately by using a coil antenna alone with proper balancing. Afterwards it is possible to determine **on which side** the transmitting station is located by a "**Unilateral**" method.

27. The usual way to accomplish this is to use a short vertical wire antenna erected along the axis of the coil, this vertical antenna being coupled to the coil antenna with a variable coupling as shown in Fig. 6. A radio wave coming from the left would cause current to flow in the vertical wires comprising the **left** side of the coil, say in a downward direction at some particular instant. A corresponding current would be induced in the vertical antenna and, through the variable coupling would add its effect to the current flowing in the coil circuit, thus increasing the amplitude of the received signal. Now as the coil is rotated through an angle of 180°, the electromotive force induced in the coil antenna is reversed in phase, while there is no change in the induced electromotive force of the vertical antenna. The two induced electromotive forces would then oppose each other in the variable coupling and the received signal would be reduced in amplitude. That is, the current through the variable coupling would be 180° different in phase for waves approaching from opposite directions. The direction of flow of current in the vertical antenna and its part of the coupling is independent of the direction from which the wave comes so that its effect will be additive for waves from the right and subtractive for waves from the left.

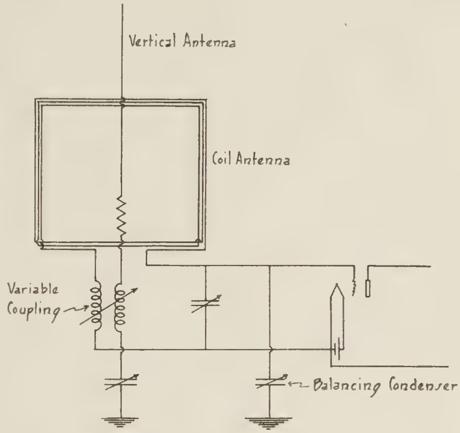


Fig. 6.—Radio Compass for Unilateral Reception.

28. The coupling between the two antenna circuits is adjusted until the strength of the signal from the antenna alone is the same as the strength of the signal from the coil alone when the coil is in position for maximum signal. Under these conditions the directional characteristic of the combined systems is as shown in Fig. 7. In this figure the small dotted circles are the symmetrical directional characteristics of the coil alone. The coil is shown as a heavy line at L_0. The large dotted circle is the directional characteristic of the vertical antenna alone. The resultant characteristic is the curve shown in full line passing through B. It is evident that for a wave approaching, from B a good signal will be received while for a wave approaching from "A" practically no signal will be heard.

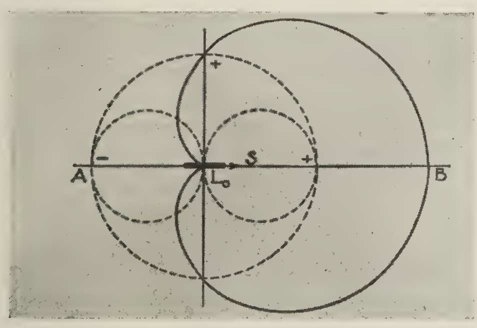


Fig. 7.—Directional Characteristic of Unilateral Radio Compass.

29. **CALIBRATION.** It has been found that the wave front is usually distorted when it reaches the coil antenna due to the presence of nearby buildings, trees, or metal of any kind in the path of the wave, so that the direction indicated is different from the true direction of the sending station.

Where it is impossible to eliminate these sources of distortion, it is necessary to **calibrate** the receiving station so that the proper correction can be applied to the observed bearing. A shore radio compass station can be easily calibrated by having a ship steam on a circular course in sight of the station, simultaneous readings being taken of her bearing by radio and visual. Separate calibrations are necessary for each appreciably different frequency used.

30. Calibrating a radio compass aboard ship is carried out somewhat similar to swinging ship for obtaining deviations of a magnetic compass by the method of bearings of a distant object. The ship heads on the courses desired at a distance of a few miles from a radio station, simultaneous radio and visual bearings of the station being taken. The deviations are plotted in a curve similar to that of a magnetic compass. Readings are taken in degrees from the bow of the ship to the right so that to get the compass bearing, this angle must be applied to the ship's course. When the radio bearing is **greater** than the true bearing, the deviation is negative.

31. **COMPENSATION.** Aboard ship it is impossible to find a location for the radio compass that is not adjacent to some mass of metal or other source of distortion. The radio compass is placed, however, so that it is as free as possible from such influences and any leads in the rigging of the ship in the vicinity that might act as an antenna are insulated from the metal of the ship. Means of compensating radio compasses have recently been developed. As a result the maximum error of shipboard compasses have been greatly reduced. This is important, for large deviations usually mean broad minima, and broad minima give inaccurate bearings. A **broad** minimum is usually understood to be one which, due to poor signal strength, gives a broad angle of no audible signal. A **poor** minimum is one which never exactly reaches zero, or one whose zero point is not sharply defined and constant. Shipboard compasses are almost invariably located on the fore and aft center line of the ship and usually between two steel masts, or between a mast and a stack.

32. The worst deviation is on the beam for the following reason. The wave, coming from a direction off the beam and cutting the hull of the ship, the mast, stacks, etc., causes certain induced E.M.F.'s in these which will cause currents to flow. Under the loop this current flow will generally be in a fore and aft direction which means that the magnetic field will be such as to cut the loop so as to induce in it a maximum voltage (the plane of the loop lying in a fore and aft direction for beam bearings). It is evident that the bottom conductors of the loop are more closely coupled to the hull than are the top conductors. If, therefore, the top of the loop could be coupled to a horizontal conductor so as to induce in the loop an equal E.M.F. it would be counter to that induced in the bottom of the loop, and this cause of deviation would be practically balanced out. This is accomplished on board ship by passing very low resistance cables directly over the loop in a fore and aft direction and grounding them to adjacent masts or stacks. By varying the number and height of the cables the error is reduced to a minimum. These cables also cause the currents flowing in the vertical members of the ship (masts, stacks, etc.) adjacent to the loop to be equalized (or partially so), thus inducing equal voltages in the opposite vertical sides of the loop which cancel each other.

33. The above correctors afford means of correcting errors caused by conductors more or less symmetrically placed with respect to the compass loop. There are usually other conductors not symmetrically placed, and also various closed loops about an iron ship carrying currents induced by the signal. These loops, through induction, set up E.M.F.'s in the compass loop, the values of which depend on the relationship of the plane of the compass coil with these fields. These E.M.F.s may be combined into one resultant E.M.F. which may have any phase angle with the signal voltage acting around the compass loop. This resultant E.M.F. may further be resolved into two components.

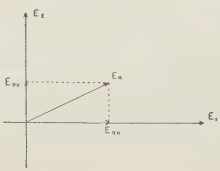


Fig. 8. Voltages Induced In Compass Loop.

34. In Fig. 8 let E_1 be the voltage induced in the compass loop due to its antenna effect, E_2 the signal voltage acting around the loop, and E_R be the resultant voltage due to the various closed loops about the ship. With a rotation of the compass loop, E_R may change in magnitude and phase angle, and may reverse (due to change in coupling with the closed loops). The value of E_2 will also change with rotation of the loop. E_1, being the voltage due to the antenna effect, will remain constant. For the conditions shown in the figure the resultant E_R may be resolved vectorially into two components, the vertical E_{RV},

and the horizontal, E_{RH}. The vertical component can be taken care of quite easilyby rotating the loop to a point where we get a value of E_2 equal but opposite in phase to E_{RV}, thus eliminating the vertical component. This amount in degrees, that the axis of the loop winding has to be turned away from the direction of the incoming signal is the deviation due to the causes just discussed and cannot be corrected. Fortunately it is small in comparison with the other errors that can be corrected; especially when care has been taken to break all stack guys, etc., by means of insulators, thus reducing the number of these loops.

35. The horizontal component E_{RH} and the antenna effect E_1 do not produce deviation, but they are the primary causes of poor minima and hence inaccurate bearings. E_{RH} and E_1 are compensaaed for by means of the compensating or balancing condenser, previously discussed in this chaptetr. Conditions sometime prevail, however, when the capacity of the compensating condenser would h ave to be prohibitively large to obtain a balance. For instance, if the horizontal component, E_{RH}, (Fig. 8), is greater than the voltage, E_1, due to the antenna effect of the loop, a balance could not be obtained with any practical value of the compensating condenser. The only thing left to do is to make E_1 larger. This is done by adding a vertical antenna, the lower end of which is attached to the mid-point of the loop, but not inductively coupled to it.

36. **RADIO COMPASS STATIONS.** There are about fifty Radio Compass Stations distributed along the coasts of the United States including Alaska that are operated by the Navy. Many foreign countries also operate such stations. Ships at sea make use of these stations, the bearing of the ship from the station being supplied on request. Frequently a number of stations operate in groups, a request for a bearing being answered by bearings from two or three stations so that a "fix" can be obtained.

37. Radio Compass Stations operate on a frequency of 375 kcs. Usually three stages of radio frequency, a detector, and two stages of audio frequency are employed in the sets. It must be remembered that the bearings given by the radio compass stations are "great circle" bearings and should be plotted accordingly if the ship is very far from the station.

38. **ANTENNAS OF SUBMARINES.** The coil antenna can be used to advantage on submarines where the ordinary elevated type of antenna is impracticable when the submarine is submerged. The arrangement is shown in Fig. 9. The hull of the ship serves as the lower part of the loop, the upper part consisting of insulated wire which is connected to the hull at the bow and stern respectively. The lead-in wires are brought in through the conning tower as shown so that the loop is inverted as compared to those shown in other figures. The action, however, is the same in each case.

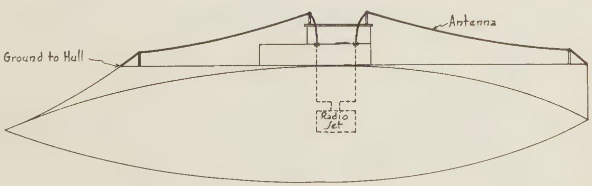


FIG. 9.—Arrangement of Antenna of Submarine.

39. **COIL ANTENNA ON AIRCRAFT.** Coil antennas may be used on aircraft not only for plain receiving but also for direction finding work. A number of turns may be wound on the wings as a coil antenna, or in the case of large airplanes, a small rotatable coil may be used.

40. **COIL TRANSMITTERS.** Coil antennas can be used for transmitting as well as receiving but they are only used in special cases such as that of a submarine submerged where it is impracticable to operate with the elevated type. While the radiation has a marked directional characteristic, this feature does not have the advantages that directional receiving has. Consequently it is not used to any great extent.

41. **BEAM TRANSMISSION,** possibly more properly called **directed** transmission, has been developed with the increased use of high frequencies (short waves). This method of transmission uses some sort of a reflector which attempts to confine the radiation to a sector (beam) of relatively small angle, extending in the direction it is desired to communicate. Other methods, some of which use coil antennas, have been tried but the reflector type is most common. Directed transmission is

practical only with the higher frequencies, due to the prohibitively large reflectors and antenna systems that would be required for the lower frequencies. It is most suitable for long distance point to point communication, and, due to the necessity for pointing the beam, is not practicable for shipboard use.

42. **NATURE OF BEAM.** The angular width of the beam commonly varies from 15° and 30°, but Marconi claims to have reduced this width to less than ten degrees in some cases.

Practically, there is no direction in a horizontal plane in which absolutely no signal is radiated. The stated width of the beam depends upon what the "edge" of the beam is considered to be, and, in general, the angular distribution of sky wave leaving an antenna system is **not** the same as the angular distribution of the ground wave. The true nature of the beam would require a statement in solid angles and three dimensions to describe it.

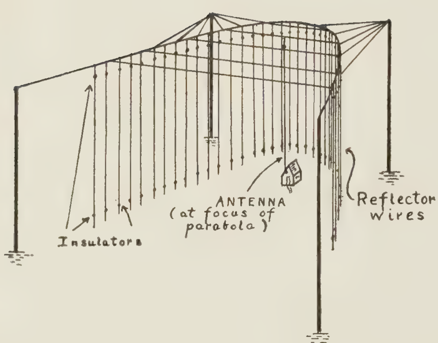


Fig. 10. Parabolic Type Reflector.

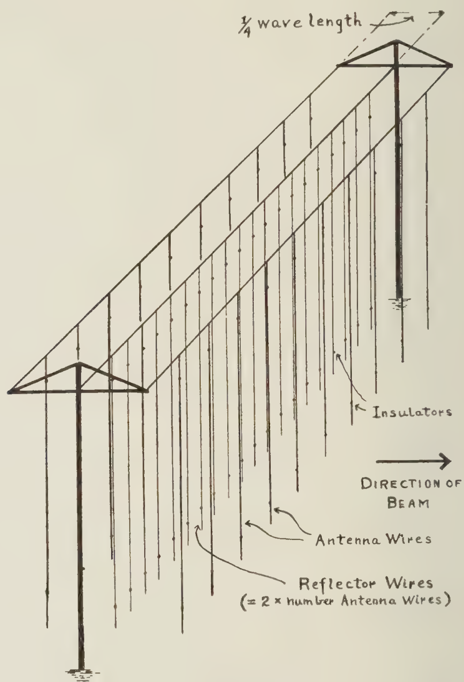


Fig. 11. Grid Type Reflector.

43. **TYPES OF REFLECTORS.** The two principal types of reflectors in use are shown in Fig. 10 and Fig. 11. In the **parabolic type**, Fig. 10, the vertical transmitting antenna is placed at the focus of an arrangement of vertical reflecting wires arranged in the shape of a parabola. In the simplest system each of the vertical wires is tuned to the frequency of the transmitting antenna.

This type is rapidly being superseded by the **grid type** shown in Fig. 11, which is simpler and easier to construct. The antenna wires are all excited by the transmitter through an arrangement which adjusts the phases of oscillation in the various wires so that the radiated waves combine to give a beam such as that projected by the parabolic type of reflector. An additional advantage of the grid type of reflector is that another set of antennas may be placed on the other side of the reflector wires, as indicated in the figure, so as to transmit the beam in the opposite direction. Either set of antennas may be used.

44. The greatest advantage of beam transmission is one of economy rather than one of secrecy. With a properly constructed reflector, from 50 to 100 times the energy is received at the receiving station over that received from a simple vertical antenna using the same power. If a similar reflector is used by the receiving station a moderate increase of signal strength is noted, accompanied by a large increase of signal to noise ratio. The same distance can be covered with much less power when using the directive types of antennas.

CHAPTER XVII

INTERFERENCE AND SELECTIVITY

1. **INTERFERENCE, PHYSICAL CAUSES.** As substantially all radio equipment includes tuned resonant circuits, and the results that we get in these circuits depend upon various electrical impulses applied to them, an understanding of their action may be had by considering the effects of various types of impulses or forces applied to a mechanically resonant device such as one of the musical instruments.

2. It is, for example, a matter of common knowledge that a bell may be caused to ring by hitting it with any kind of a hammer. There is no necessary relation between the note given out by the bell and the kind or size of hammer that is used. About the only kind of relationship to be noticed is that the harder we hit the bell the more loudly it rings. A condition closely corresponding to the above is found in electrical circuits. If a resonant circuit is given an electrical blow it will start ringing, or "oscillating" as we call it, at a frequency which depends only upon the electrical constants of the circuit and not at all upon the exact nature of the electrical blow. The same blow delivered to various circuits will cause each to oscillate at its own particular frequency. Such an electrical blow is deliberately produced in some of the older types of damped wave transmitters. It is also produced by static in all of our receiving sets. It should be seen from the above that tuning or changing the resonant frequency of receiving equipment can be of but little use in eliminating the effects of static. The resonant circuit merely oscillates at whatever frequency it happens to be tuned to. It should also be remembered that in an ideal resistanceless circuit this oscillation when once started would continue indefinitely. In the practical circuit the number of cycles that occur in such an oscillation before it drops to a negligible percentage of its original value depends entirely upon the decrement of the circuit. If the decrement is high but few cycles occur, if very low a large number of cycles.

3. From the ordinary point of view a hammer blow has no particular frequency. From the mathematician's point of view, we might rather say that it partakes of all frequencies within the range over which the pitch of the bell to be rung by it could vary. Similarly an electrical impulse has no particular frequency from the simple point of view. However, it is convenient to consider that it partakes of all frequencies over an enormous range, since, if it is applied to a resonant circuit having a natural frequency of almost any value a current of the resonant frequency for that particular circuit will proceed to flow.

4. A single impulse of the kind described above always creates some disturbance or **"interference"** in a receiving set if the set is so arranged that it will receive from the direction from which the impulse comes. In other words the only means which permits a receiving set to avoid being operated by an impulse is some means which refuses to receive anything at all from the particular direction from which the impulse comes.

5. In the preceding paragraphs the results of single impulses have been considered. These single impulses are of the worst type so far as the production of interference is concerned; in fact, their interfering qualities are such that no attempt is made to use them in the antenna of any transmitting set. (The type of set before referred to uses the impulse only in a closed circuit.)

6. All practical radio transmitters have an antenna current which consists of groups of impulses, the impulses being equally spaced and occurring at a radio frequency. Normally there will be a large number of impulses in each group. It is highly important that the difference in results between a single impulse and such a group of impulses be understood.

7. Let us consider the possible results of hitting a bell two blows with a small hammer, the second blow occurring while the bell is still ringing from the first blow. A little thought will point out that the result of the second blow will depend upon what the bell happens to be doing at the instant that the hammer strikes it the second time. The second blow might, for example, occur at just the right

time to tend to stop the motion of the bell. In this case the result would be a weak vibration of the bell corresponding to the difference between the motion left with the bell from the first blow and the motion which the second blow would have produced had the bell not been in motion. It should be noticed here that the magnitude of this difference (if the two hammer blows were equal) depends among other things upon the rate at which the vibration of the bell dies out, (in other words, upon the mechanical decrement of the bell). If the vibration had not died down at all the final motion would be nothing for equal blows, while on the other hand if the vibration had practically died out the second hammer blow would necessarily produce practically the same results as the first one.

8. The other extreme case so far as the time at which the hammer blow occurs is concerned would occur when the second hammer blow is so timed that it is all expended in assisting the motion which the bell has left from the first blow. The final result in this case is again seen to depend upon the mechanical decrement of the bell. If the decrement is low so that the bell is still ringing at practically full amplitude the final result will fall but very little short of being the sum of the two blows (or in other words will be nearly the same as though there had been just one blow with twice as much energy in it). Again, if the decrement of the bell is very high the vibration immediately after the second blow will depend almost entirely on the second blow as there would be almost nothing left from the first one.

9. In electrical circuits an exactly similar condition exists. The result of a series of impulses **may actually be much less** than the result from one of these impulses alone, or the result of the series of impulses may be a final result practically equal to the sum of the separate ones. (When the latter result is obtained resonance is said to exist.) These are the two extreme conditions. It should be particularly noticed that both the timing of the impulses and the decrement of the circuit enter into determining what the result will be.

10. Above, the two extreme conditions in the timing of impulses have been considered. It is now important to consider the effects obtained if the timing of the impulses is **almost** but not quite right for the production of a continuously cumulative effect. Let us consider a series of impulses acting upon a circuit having very low decrement. It is assumed that the applied impulses occur just a little too frequently for **continuously** cumulative results. Since the discrepancy in timing of the impulses is small the second impulse will occur at practically the right time for a strictly cumulative result. The third impulse will be a little further out and so on up until the time when there is neither direct addition nor direct subtraction. (The impulse occurring at this time is leading the current in the oscillating circuit, due to the original impulse, by 90°.) Beyond this point the new impulses begin to subtract from the original oscillation current, and presently the incoming impulse is 180° from the current produced by the original impulse. It should be noticed that the result of the original impulse and the one occurring at this time is a simple difference and the result of these two depends as before upon the amount that the original has decreased in the meantime.

11. In an ideal case (zero decrement) the current due to the original impulse would not have decreased and its effect would now be wiped out by the incoming impulse (assuming all impulses of equal magnitude), thus leaving a result roughly proportional to the number of cycles necessary for this 180° slip in phase to occur. On the other hand, if the decrement happened to be very high, the effects of the first impulse might be practically gone, so that this last impulse would have nothing to oppose it. The amount by which the original impulse current will have decreased by the time that the incoming impulse gets around to exactly opposing this current depends then upon two things—the decrement and the amount by which timing fails to correspond to the natural frequency of the oscillating circuit. The smaller the decrement the more nearly can a succeeding impulse wipe out the effect of some preceding equal one. The greater the difference in timing the sooner will the applied impulse be 180° out of phase with the original impulse current. Of course the maximum result is produced in an oscillating circuit when the incoming impulses are continuously produced at the right time to add their effect to the existing current. Resonance is said to exist when this condition occurs.

12. **SELECTIVITY.** Selectivity is a measure of the ability of a receiving set to select a certain signal while excluding others. The expression that a certain set is highly selective means that with a given kind of received signal it is better able to exclude interference than other sets with the same signal and same interference. If a quantitative measure of this selectivity is desired it is made to depend upon the **ratio** between the strength of signal and interference, other things being the same. It is obvious that interference could be eliminated completely by shutting down the set, but it is equally obvious that this is quite useless and would not indicate that the set was selective.

13. Selectivity of receiving equipment may in general be divided into two classes. The first depends upon some type of signal collecting system which operates more effectively for signals (or interference of any kind) from some directions than for similar waves from other directions. This is decidedly useful in reducing interference that does not happen to come from the same direction as the desired signal. The simplest form of collector that shows the above characteristic is the loop antenna. A combination of a loop with an ordinary antenna is still more useful in eliminating nearly everything from an appreciable sector of the horizon. A special type of low antenna preferably one or two wave lengths long is known as a Beverage antenna. It has highly desirable directional characteristics but is inconvenient to install even on land on account of the necessary length.

14. The second class of selectivity depends upon the ability of tuned circuits to respond more strongly to the resonant frequency than to other frequencies appreciably different from the resonant frequency. This is known as frequency (or wave length) selectivity. It should be noticed that there is no sharp line of division between the frequencies that will be received and those that will be rejected. As a matter of fact it is always possible to at least compute the response for any voltage and frequency different from the resonant frequency. Here, again, the selectivity of a receiver depends upon the **ratio** between the results at resonant frequency and the results at the other frequency being considered. The greater the ratio the more selective the set is considered to be. While it might be possible to compute the necessary values to give any desired selectivity with a continuous wave and a single circuit, these values cannot be obtained practically, if the desired selectivity is high. The result of this is that it becomes necessary to use two or even three tuned coupled circuits to obtain high selectivity.

15. The nature of the action here is that while the first circuit might reject only half of the undesired signal the second circuit if similar would reject half of what was left and a third circuit again might reject half of that remainder, thus leaving only one eighth of the interference with the three circuits compared to one half with one circuit. The ordinary radio frequency amplifier gives some gain in selectivity on the above principle, as there are a number of coupled circuits in the amplifier, and each of these circuits operates effectively over only a limited range of frequencies.

16. As explained under heterodyne reception, heterodyne reception lends itself to greater selectivity than ordinary reception. Audio frequency tuning may be utilized to obtain an increase of selectivity, but is not in common use for ordinary reception directly with a head set. Certain types of automatic receiving apparatus utilize audio frequency tuning in addition to the usual tuning. Due to the nature of **any** tuned circuit it requires an appreciable number of cycles for the building up of current and after the applied voltage has been removed an oscillation gradually dies out during a similar number of cycles. This evidently introduces a lag which becomes more and more serious as the frequency of tuning becomes lower and as the speed at which it is desired to transmit becomes higher. The results of this are particularly prominent with audio frequency tuning, but it must be considered even with the lower radio frequencies when very high speed (several hundred words per minute) transmission is attempted.

17. **FREQUENCY REQUIREMENTS FOR SIGNALLING.** In order to transmit signals by means of an electrical current, the current must repeatedly be changed. Regardless of what code is used, this repeated and more or less systematic changing of current can be analyzed and found to require (or contain) a variety of current frequencies. If this current is to be transmitted through **any** kind of a circuit and the received signal is to be the same as the transmitted one except for

magnitude this circuit must be capable of transmitting all of these frequencies equally well. If the circuit fails to transmit some of the frequencies as well as others the signal received must differ in some respect from that sent out. While not all frequencies sent out may be necessary for an intelligible signal, a certain range of frequencies is always necessary. This range in the simplest case might be from zero up to some small value. However, these low frequencies can not be used directly for radio transmission. This difficulty is overcome by means of various types of radio equipment which simply transfer the range of frequencies required to some other part of the total range of frequencies. For example, if frequencies from zero up to one hundred cycles per second are required for a definite type of telegraph transmission over an ordinary telegraph line, for radio transmission of these signals apparatus will be used which, when controlled by these low frequencies, may turn out frequencies from 1,000,000 up to 1,000,100. This is the ideal case.

18. Considerable difficulty is encountered in confining the radio frequencies to a range less than twice as wide as the original. With the higher radio frequencies this difficulty is such that the usual radio transmitter is permitted to turn out a double range. In the above case for example the practical transmitter would turn out not only the range from 1,000,000 up to 1,000,100 but also a sort of inverted range running from 1,000,000 down to 999,900. The receiver is able to utilize both of these, so that the second one is not entirely wasted. It should be particularly noticed that the **range** of frequency required is ideally the same regardless of where that range is located. Apparatus can be made which closely approaches this ideal, but almost all practical equipment not only radiates the double range (which is all useful at the receiving end) but also radiates a more or less appreciable quantity of other frequencies which not only are entirely useless but frequently are a cause of serious interference to stations which are trying to receive other signals.

19. **PARALLEL RESONANCE.** For radio applications parallel resonance may be said to exist when the total current supplied to a capacity and inductance in parallel becomes a minimum due to the variation of the applied frequency or due to the variation of one of the two branches. For purposes of computation parallel resonance will be taken as the condition existing when the reactive component of current going to the inductance is equal to the reactive component of current going to the capacity. If the resistances in the two branches are equal, these two conditions are exactly the same. In the practical case where the resistances probably are not equal, but where the resistances **are** small compared to the reactances the difference is so slight that it will be neglected. It may be instructive to notice that the maximum energy stored in the capacity branch of the circuit is equal to the maximum energy stored in the inductive branch of the circuit when parallel resonance exists. This is expressed mathematically by $I_L^2 X_L = I_C^2 X_C$. This same condition exists in a series resonant circuit.

20. **IMPEDANCE OF PARALLEL RESONANT CIRCUIT.** The computation of the impedance of a parallel resonant circuit is a simple application of AC theory. It is suggested that it be obtained by assuming some convenient voltage (perhaps 100 volts) across the parallel circuit, computing the current through each branch, taking the vector sum of the two branch currents to obtain a line current, and then dividing the line current into the assumed voltage to find the impedance. It should be noticed that the amount of resistance in the circuit has a large effect upon the value of the line current obtained, and consequently a corresponding effect upon the impedance of the parallel circuit. It should be specially noticed that within the useful range of values, the larger the resistance, the **greater** is the **line** current. The corresponding effect with impedance is that the **larger** the resistance of the branches the **smaller** is the impedance of the parallel resonant combination. An impedance computed as above holds accurately for the frequency for which it was computed so long as a steady voltage is applied (continuously).

21. A single impulse (even if made to resemble a half cycle of the frequency for which the circuit is resonant) will **not** meet with an impedance such as that which would be computed by the method suggested above. Such an impulse initially will pass through the capacity branch almost entirely, but will proceed to start an oscillation in the closed circuit consisting of the two branches now considered in series. If there is just one impulse applied it will be found that not only does the

parallel resonant circuit not greatly impede the initial impulse, but the parallel circuit will proceed to apply a damped oscillating voltage to the rest of the circuit **after the impulse has gone.** If repeated impulses are applied at the proper intervals (as determined by the resonant frequency) an oscillating current will be built up in the closed circuit, consisting of the two branches, and, after quite a number of impulses or cycles, will become large enough so that the e.m.f. which it applies to the rest of the circuit is almost equal to the e.m.f. applied in the external circuit. This latter e.m.f. is opposing the applied e.m.f. Its existence explains the apparently disproportionately large impedance of the parallel resonant circuit. This counter e.m.f. and the fact that it is **gradually** set up and **gradually** dies out should make it clear that as an impedance a parallel resonant circuit becomes less effective if the amplitude of the applied voltage is changed rapidly.

22. Observations of current in the main circuit and in each of the two branches will show that at resonance the current in each branch is much greater than the current supplied from the main circuit. This apparent impossibility is most easily explained by considering it to be due to a circulating current set up **around** the parallel circuit. (It should be noticed that so far as this circulating current is concerned the so-called parallel circuit is actually a series circuit. At the same time, from the point of view of the current arriving through the line, this circuit is truly a parallel circuit.)

23. Since the impedance of the parallel resonant circuit depends principally upon the building up of a current around the parallel circuit, the results obtained if the applied frequency is slightly different from the resonant frequency will differ from the resonant condition for the same reason that the results in the series resonant circuit differ as the applied frequency is changed. With an applied frequency slightly different from the resonant value a current will start to build up circulating around the circuit, but before a value corresponding to the resonant condition can be reached, the applied e.m.f. will have dropped out of step with the current which has built up, so that the effect is not continuously cumulative.

24. The parallel resonant circuit provides a device which tends to pass currents at all frequencies but one, the resonant frequency, and tends not to pass that one at all. There is, of course, no sharp cut off as we depart from the resonant frequency. In order that a usefully rapid change in impedance may be obtained with changing frequency it is necessary that the building up of current circulating around the circuit shall continue for a relatively large number of cycles. This requires two different things. In the first place, the decrement of the oscillating circuit must be low. In the second place the applied e.m.f. must contain a corresponding relatively large number of consecutive cycles of substantially equal amplitude. This principle is used in various wave-trap circuits, and was formerly used as the "Acceptor-Rejector" circuit in the Navy.

25. **FILTERS.** The name filter has long been applied to a device for separating various sorts of finely divided solids from liquids. In general it might be said to be a device for separating things having different characteristics.

26. The electrical filter is a device for separating electrical currents having different **frequency** characteristics. The electrical filter which is able to draw a fairly sharp dividing line between the frequencies that it separates is made up of a network consisting principally of inductance and capacity. Such a network will, of course, have some resistance, but this is merely a necessary evil. The resistance is not desired at all and is kept to the smallest economically feasible value.

27. Combinations in which resistance plays a controlling part may be made up, but such a circuit never changes **abruptly** from an accepting to a rejecting state. It is said to have no definite "cutoff." While this type of device is sometimes called a filter, the name is usually used with the capacity inductance network.

28. Filters utilize a combination of three things, which have been explained separately. These three are, series resonance, parallel resonance, and coupling phenomena.

29. Four types of filters which may be mentioned are known respectively as "High Pass," "Low Pass," "Band Pass" and "Band Rejection" filters.

30. The ideal operating condition for a filter has a certain resistance load connected to the filter (for which the filter was designed). In a **high pass filter** all frequencies higher than a certain value (known as the cutoff value) pass through the filter readily, while all frequencies below this value meet an enormous impedance when attempting to pass through the filter. Of course there is some transition range in which intermediate values of impedance are presented by the filter, but it is possible to so construct a filter that this transition range is a small percentage of the cutoff frequency.

31. The **low pass filter** differs from the high pass in that it freely passes currents of a frequency **below** the cutoff value, while presenting large impedance to currents of higher frequencies. Note that a low pass filter will pass direct current. (From the mathematicians point of view, direct current is an alternating current of zero frequency.)

32. In the **band pass filter,** currents of frequencies between two definite cutoff values pass readily, while high impedance is presented to the passage of frequencies either below the lower limit or above the upper limit.

33. The **band rejection filter** is the opposite of the band pass filter. In this case high impedance to current passage is found **between** the cutoff values, and frequencies below the lower or above the upper cutoff value pass readily.

34. One of the simplest forms of circuit used as a filter is shown in Fig. 2. This is a variety of low pass filter. Such a filter is commonly used between a DC generator or rectifier and the input to the plate of a VT generator circuit. In this case L and C are made of such sizes that the "cutoff frequency" for the combination is much lower than the lowest frequency of disturbance that needs to be eliminated.

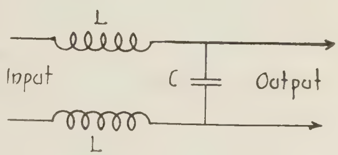


Fig. 2.—"Brute Force" Filter.

35. With such a combination as this having only one section, and in which little attention is paid to getting the load resistance at a value equal to the best value for operation of the filter, the cutoff does not occur sharply. It is for this reason that the cutoff value must be much below the lowest frequency to be eliminated. For example, it might be found that the power supply (unidirectional but more or less pulsating current) has a ripple at a frequency of 60 cycles per second. There are other higher frequencies present in the current to be filtered, but no lower ones. A value of 10 per second for a cutoff frequency would be satisfactory here. Such a filter is popularly referred to as a "brute force" filter since it functions principally by virtue of much inductance and much capacity, rather than by a complicated circuit. Possible values for an ordinary brute force filter would be L equals about 30 henries and C equals 4 μf.

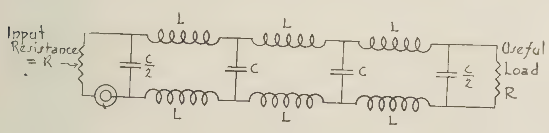


Fig. 3.—Three Section Low Pass Filter.

36. Fig. 3 shows another low pass filter. This is a filter having three sections, each section consisting of an inductance L in each side of the line. and two capacities $C/2$ shunted across. It is necessary to use some such filter if a fairly sharp cutoff is desired. Failure to have the proper value of resistances at the ends of the filter interferes with the sharpness of the cutoff, but may be compensated for by putting more sections into the filter.

37. At the present time filters are extensively used in communication over land wires. Only brute force filters are extensively used in the Navy.

38. **COUPLING TUBE SYSTEMS.** In the large majority of cases it has been desired that any radio frequency circuit should respond most strongly to a relatively narrow range of frequencies. In such cases the resistance is kept small compared to the reactances of the circuits. If it is desired to have a circuit respond to somewhere near the same extent to a wide range of frequencies the simplest thing to do is to make the resistance of the circuit large compared to the reactances. If the circuit is an antenna, the inductance and capacity are fixed, and the resistance normally small. In this case to make the resistance large compared to the reactance it is necessary to add a large (non-inductive) resistance in series with the antenna circuit.

39. Such a resistance of course absorbs a large part of the energy of a received signal, but at the same time it absorbs an equally large part of static and other sources of interference, so that it does not change the ratio of strength of signal to interference. The absorption of received energy merely requires that more amplification be used in the receiving equipment.

40. Having provided an antenna which responds to about the same extent to a large range of received frequencies, it appears that it should be possible to receive several different messages simultaneously on the one antenna, if means are provided for separating them after they are picked off of the antenna. To be practicable such a system must be so arranged that adjustments made for the reception of one frequency do not seriously affect the adjustments of other equipment provided for the simultaneous reception of other frequencies.

41. A system which fulfills the above requirements is shown in Fig. 5. Here R is a resistance of maybe several thousand ohms, the IR drop across this resistance is impressed upon the grids of as many tubes as it is desired to have simultaneous receptions. Current variations occur in the plate circuits of these tubes corresponding to the voltage variations impressed upon the grids. These current variations provide a source from which the receiving set is operated. The only coupling between two different receiving sets is through the capacities of the elements and connections of the tubes. This coupling does not prevent satisfactory operation. While the prime object of one of these tubes, known as a **coupling tube,** is to couple the antenna to one receiving set while avoiding coupling between the various receivers, the tubes also provide some amplification of received signal. This is **not** enough to make up for the loss due to the added resistance.

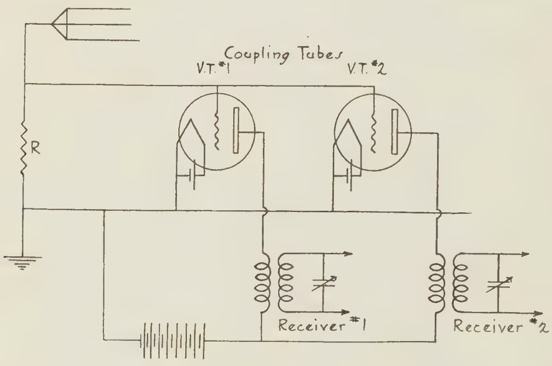


FIG. 5.—Receiving System Using Coupling Tubes.

42. **NECESSARY ACCURACY OF CALIBRATION OF TRANSMITTING AND RECEIVING SETS.** Reception of CW is practically performed only by the beat method. The beat frequency that gives the best results for reception with a head set is about 1000 cycles per second. With low frequency transmitters this represents a considerable percentage of the transmitted frequency. For example, the lowest radio frequency used for transmission is about 12.5 kcs. One thousand cycles is 8% of this. There is very little difficulty in setting such a frequency on either transmitter or receiver within a few hundred cycles. On the other hand, with the high radio frequencies the percent difference represented by 1000 cycles is correspondingly smaller. For example, at 5000 kcs. we see that 1000 cycles is only 0.02% of the carrier frequency. The difficulty of setting the transmitter to within a few hundred cycles of such a frequency as this is great, but the necessity is the same as with the lower frequencies.

43. It has been decided arbitrarily that 350 cycles shall be the limiting error of calibration, beyond which operation is considered unsatisfactory. It might well be noted that if the maximum

error of 350 cycles exists in both the transmitter and the receiver the tone heard in the head set when both are supposed to be set for transmission with a certain frequency may be as high as 1700 cycles or as low as 300 cycles. Both of these are far enough away from the frequency for maximum sensitiveness of the phones and the ear to considerably decrease the readability of a weak signal.

44. The frequency generated by a VT generator depends principally upon the effective inductance and capacity of the oscillating circuit, but it also depends to some extent upon a number of other things, such as filament emission, plate voltage, closeness of feedback coupling, losses in the grid circuit, and the L/C ratio in the circuit. While the frequency generated with a VT circuit when no changes occur in the above is even more nearly constant than required, it is not at present feasible in the higher frequency sets to keep all of these things near enough to a constant value during long periods of time. A specially arranged VT generator in which these variations are minimized may be used to set apparatus to the desired frequency. Such a calibrated VT generator is known as a heterodyne frequency meter. Equality of frequency is determined by setting the unknown transmitter to give zero beats with the calibrated transmitter. See Chap. XI, par. 25 to 37.

CHAPTER XVIII

NAVAL RADIO APPARATUS

1. The foregoing chapters have covered the fundamental principles on which radio communication is based. In applying these principles, numerous combinations can be made, and this has resulted in a large variety of radio sets which differ in their details depending on the particular service for which they are designed.

2. In the Navy, most radio communication is carried on by telegraph code. Both damped and undamped waves are used though the present tendency is to eliminate damped waves. Provision is also made for simultaneous communication with shore stations, with different detachments of the fleet, with ships cruising in the same formation, with airplanes accompanying the fleet, etc., so that several transmitting and receiving sets are usually necessary where the size of the ship renders it possible. Simultaneous sending and reception is also accomplished using a number of different frequencies.

3. The largest ships usually are supplied with transmitting sets having a maximum range of about 1,000 miles daylight transmission using telegraph code. Destroyers and smaller craft have equipment with a range of about 500 miles daylight transmission. For short distances, interfleet work, communication with spotting planes etc., a set with a range of about 150 miles is considered sufficient.

4. The Bureau of Engineering's **"Instructions for the Operation, Care, and Repair of Radio Plants"** and Robison's **"Manual of Radio Telegraphy and Telephony"** both of which will be found on all ships, give detailed description of and instructions for operation of most of the sets in use in the Navy. The details of others are covered in special pamphlets which accompany the installation.

TRANSMITTING SETS

5. The present policy of the Navy Department is to replace all arc sets, spark sets, and buzzer sets on board ship with Vacuum Tube sets. It will take a number of years to complete this, however, and many of the sets mentioned above will still be found on naval ships. The present policy in the Fleet is to prohibit the use of spark sets on naval ships except in an emergency.

6. For **Long Distance** transmission, the arc set which used to be standard, has been replaced by V.T. transmitters. Battleships fitted as flagships are usually equipped with 5 kw. sets, 500 cycle 10,000 volt plate supply. Scout cruisers, large oilers and colliers usually have 2 kw. sets. On transports, 2 kw. sets are usually installed and a few scattering 5 kw. sets have been placed on different vessels.

7. The arc sets where installed are similar to the one described in Chapter VI, the difference being principally one of size only. The **Uniwave** or Absorption method is used and they operate on frequencies of 75 to 100 kcs. for the higher power sets, and 100 to 550 kcs. for the smaller sets. Some of the smaller sizes are equipped with choppers but they are not generally used.

8. For **Medium range** transmission, spark sets have been extensively used in the past but these are now being replaced as rapidly as possible by vacuum tube transmitters. As mentioned above, the present policy is to prohibit their use except in an emergency. The type of spark set generally found on naval ships is the 500 cycle 1, 2, and 5 kw. quenched spark transmitter which is briefly described in Chapter V. A 2 kw. spark set is usually kept in reserve for use after an action, storage batteries being used to supply the necessary power.

9. For **Short distance** low power transmission buzzer transmitting sets were formerly used but these are rapidly being replaced by vacuum tube sets. Portable field sets of 1/4 kw. power are sup-

plied to the larger ships for portable use. These are small spark sets with an alternator driven either by an internal combustion engine or by hand.

10. **VACUUM TUBE TRANSMITTERS.** This type of transmitter is rapidly superseding the arc and spark sets. It not only generates a purer wave and thus eliminates considerable interference but is also more flexible in use. Types of vacuum tube sets are generally designated by two letters, the first letter being "T." They are made so that they can be used for transmission using (a) Continuous waves, or (b) Interrupted Continuous waves.

11. For **RADIO TELEGRAPHY,** continuous waves and modulated continuous waves are used, the heterodyne or autodyne method being used for reception. Using ICW, either heterodyne, autodyne, or simple detector is possible at the receiving end. Four methods of obtaining ICW are used, The first consists of the substitution of an ordinary buzzer in the microphone circuit of Fig. 4. Chap. XIV. The second method consists of inserting a chopper in the grid circuit of the oscillating tube. The third method is by using 500 cycle alternating current for plate supply as shown in Fig. 11, Chap. XIII. The fourth method is accomplished by modulating the grid sinusoidally with 500 cycle alternating current.

12. The **Radio Telephone** follows the diagram of Fig. 4, Chap. XIV, in its general principles. More tubes are used, however, than are shown in this diagram.

RECEIVING EQUIPMENT

13. Provision must be made for receiving CW, ICW, damped waves, or modulated CW. A simple detector circuit is sufficient to receive all of the above except CW which requires some means of converting the radio frequency continuous waves into pulses of current at audio frequencies. The beat method, either autodyne or heterodyne, is used for this purpose in preference to the chopper, tikker, or other mechanical device. The beat method is advantageous for all telegraphic code reception though not for the radio telephone. Naval receiving sets are therefore designed to receive either with or without beat reception.

14. The most common type of receiver is the one tube regenerative type. By increasing the amount of coupling of the regenerative coil or tickler until self oscillation begins, this type of set can be used with autodyne reception so that either damped waves, ICW, or radio telephone may be received.

15. The above sets include only one tube which is used as a detector. A separate unit is nearly always provided, however, which includes two tubes arranged for two stages of audio frequency amplification. This amplifier unit is transformer coupled. It is inserted in the circuit in place of the telephones. Jacks are provided so that telephones may be plugged in on the one tube as a detector, or on the detector with either one or two stages of amplification added.

16. A new type of receiver for use afloat has now been installed. This set uses one coupling tube, four stages of radio frequency amplification, a detector, and two stages of audio frequency amplification, making eight tubes in all. The detector tube is also wired for regeneration. Tests were made of a receiving set employing the super-heterodyne principle as a result of which the set will not be used. See par. 31, Chap. XII.

17. **Radio Compass Stations** aboard ship use three stages of radio frequency and two stages of audio frequency amplification. Radio compasses are fitted on most of the destroyers and on many other ships.

18. **Shore Stations** are generally fitted with both plain and loop antennas for receiving. The receiving equipment commonly referred to as a "barrage receiver" consists of the two antenna circuits and the intermediate and secondary circuits, these being arranged so as to permit of accurate tuning and adjustment to obtain good selectivity. No vacuum tubes are used in this equipment, it being designed principally to obtain maximum selectivity. This equipment utilizes the unidirectional characteristic of antenna-loop combination to reduce interference.

19. A radio-audio frequency amplifier composed of two stages of radio frequency amplification, detector, and two stages of audio frequency amplification has been used with the above.

This is a complete receiving unit except for the fact that it has no antenna circuit. When used with the receiving equipment, mentioned above, the secondary circuit terminals of the latter are connected across the primary of the transformer of the first radio frequency amplifier tube. A stabilizer (See Par. 19, Chap. XII) is fitted to prevent self oscillation in the tubes.

LOCATION OF RADIO APPARATUS ABOARD SHIP

20. On ships large enough to have more than one radio room, such as battleships, it has been the custom to have a **Main Radio Room** and an **Auxiliary Radio Room.** The first was used primarily for all distant work, while the latter was used principally for short distance communication between ships of the fleet, for maneuvers, aircraft spotting, fire control, etc.

21. The present policy is to have all receiving sets in one radio room and all transmitting sets in the other, the transmitter being operated from the receiving station by means of a relay. This policy has been put into effect on all battleships and cruisers, and also on auxiliaries fitted as flagships.

22. On battleships, from three to four telegraph keys, telephone plugs, and start-stop switches (for transmitter motor-generators) are installed on the bridge and in the conning tower, so that this number of circuits can be controlled from either of these stations.

23. **TYPICAL RADIO PLANT AFLOAT.** A typical radio plant aboard a battleship as planned for the future will include:

(a) 1 High Power Transmitter (Main set).
(b) 1 Low Power Transmitter (Secondary-Division communication).
(c) 1 Low Power Transmitter (Secondary-Battle Line).
(d) 1 Low Power Transmitter (Secondary-Fire Control).
(e) 1 Low frequency receiver.
(f) 3 Medium frequency receivers.
(g) 3 High frequency receivers.
(h) 2 Emergency Transmitters and Receivers.

THE GROUP FREQUENCY SYSTEM

24. Only one message at a time can be sent at a given frequency on account of interference. In order to avoid congestion in the fleet where the volume of radio messages is so great, it is necessary to use a number of different frequencies as channels for communication. Each of these frequencies is assigned for a certain purpose. For instance, communication with shore stations, with detached units of the fleet, with the train, between ships of the same division, with the C-in-C, with aircraft, etc., would each be carried out on a different frequency. In general, each Flag Officer of the Fleet is assigned a frequency for communications to and from his subordinates. Each Squadron Commander of destroyers has his own frequency for squadron communication. This is called the **Group Frequency** system because frequencies are assigned to groups for communication within that group The groups correspond to the units of the fleet.

25. In the above system, each vessel is required to maintain a watch on at least one frequency, usually the group frequency. The larger ships would maintain a watch on the Commander-in-Chief's frequency as well. In order to avoid having too many men on watch on all ships, certain ships are often designated to guard one or more of the other group frequencies and to act as a relay in the transmitting or receiving of messages on that frequency.

26. A battleship desiring to send a message to the Division Commander or to the Commander-in-Chief would send it direct on the frequency assigned for that purpose. But if the message was intended for a shore station, for instance, it would be sent (using the division frequency) to the ship guarding the shore station frequency. This guard ship would then relay it to the shore station using the group frequency assigned for communication with shore stations. Similarly, a vessel in a division guarding the aircraft frequency, for instance, would answer calls and receive messages from aircraft for any ships of the division, relaying them to the ship concerned over the division frequency. In battle each ship guards additional frequencies and obtains messages direct instead of through radio guards. For example, a battleship would listen for messages from:

1. The Commander-in-Chief.
2. The Officer in tactical command of the battle line.
3. The Commander of the van.
4. The Commander of the rear.
5. The Division Commander.
6. The Gunnery control observer.
7. Spotting airplanes.

AIRPLANE RADIO EQUIPMENT

27. Radio equipment of airplanes is exposed to much more severe conditions than is the case with ship or shore equipment. Extreme temperatures are encountered and it is difficult to house the equipment so as to protect it from the weather. Also it must stand considerable vibration as well as the shocks due to landing, so that a considerable strain is put on it. When it is considered that it must be shielded to prevent interference by the magneto spark and that it must be lighter than other equipment on account of the desirability of eliminating as much weight as possible, it can be readily seen that the design of these sets is a difficult problem.

28. In general, airplane equipment is designed to withstand the above conditions as far as possible, and is built as light as possible. Otherwise, airplane sets are similar to that of ship and shore stations, there being no new principles involved. Vacuum tube sets only are supplied to aircraft.

29 The generators or alternators for transmitting sets are usually driven by a fan. All of the newer types operate from a wind driven generator using a self-regulating propeller which gives a contstant generator speed. These generators furnish the current for both filament and plate circui.as of the transmitter but not of the receiver. Steps are being taken to develop a direct current genertor, which will be driven by the main engine of the aircraft and will supply current for the aircraft's lighting needs and direct current radio set, in case that type of set is carried. A wind driven generator will be required, however, in case an alternating current set is the type installed.

30. The antenna of an airplane consists of a wire which is kept wound on a reel when not in use. When it is desired to use the radio, this wire is allowed to trail behind the plane with a weight attached to the end. The metal wires, engine, framework, etc., act as a counterpoise for the antenna, this differing from the counterpoise previously described only in that the position of the antenna and the counterpoise is inverted. For high frequency transmitters, a fixed antenna strung between the wings, or between the wing tips and tail is generally used in place of the trailing wire.

31. As the use of the foregoing antenna is sometimes rather inconvenient, coil antennas are frequently installed. These may consist of a few turns wound around the wings of the plane or may be a rotating coil similar to that of the radio compass. The turns around the wings would have a marked directional effect in receiving. With the trailing antenna this effect is also apparent. When making a turn, the change in position of the trailing wire would affect the capacity of the antenna circuit to such an extent as to throw it out of tune. Transmission under these conditions would be seriously interfered with. It should be noted that spark signals will be less affected than CW signals on account of the broader band of frequencies radiated. However, interference would be much greater with spark sets. This difficulty is obviated in CW transmitters by using a master-oscillator power-amplifier system of connections and in an ACW set by using a tank circuit.

32. When a seaplane is afloat, the trailing wire antenna cannot be used. To provide for such an emergency and to also increase the range in an emergency large seaplanes are provided with an emergency equipment consisting of two collapsible kites, one for low velocity winds, and the other for high velocity. Light weight antenna wire is used as the kite string and this forms the antenna.

33. In multiple engine planes full power may be developed by the generator of the set with the airplane engine running at such a low speed that it makes little speed through the water. In a heavy sea this would enable the set which is placed in the slip stream of one engine to be used without damaging the plane by making too much headway. A separate, single cylinder gasoline engine is being developed for emergency radio use.

34. Radio compasses are installed on some airplanes. Both the maximum and minimum methods are employed depending on whether the signal is weak or loud.

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SUPPLEMENT

THE INSTITUTE OF RADIO ENGINEERS

REPORT OF THE COMMITTEE ON STANDARDIZATION

1926

CONTENTS

PREFACE

The first standardization report of the Institute of Radio Engineers was issued in 1913. This was succeeded by revised reports issued in 1915 and 1922. Since the publication of the Report of the Committee on Standardization for 1922, the Committee has been engaged in a complete revision of that report which it now presents to the membership of the Institute of Radio Engineers and others concerned with the subject. This report was adopted by the Board of Direction of the Institute on December 1, 1925.

The membership of the Committee on Standardization during the last three years has been as follows:

1923

Donald McNicol, *Chairman*

E. F. W. Alexanderson
O. B. Blackwell
L. W. Chubb
J. H. Dellinger
E. D. Forbes
A. N. Goldsmith
J. V. L. Hogan
H. W. Nichols
A. E. Reoch
M. B. Sleeper
Bowden Washington
L. E. Whittemore

1924

Donald McNicol, *Chairman*

E. H. Armstrong
L. W. Chubb
J. H. Dellinger
Lloyd Espenschied
A. N. Goldsmith
R. F. Gowan
L. A. Hazeltine
Guy Hill
J. V. L. Hogan
C. A. Hoxie
F. H. Kroger
J. H. Morecroft
H. W. Nichols
R. H. Langley
A. E. Reoch
C. H. Taylor
Bowden Washington
L. E. Whittemore

1925

Ralph Bown, *Chairman*

F. P. Andrews
E. H. Armstrong
W. R. G. Baker
M. C. Batsel
Edward Bennett
W. W. Brown
L. W. Chubb
F. C. Conrad
J. H. Dellinger
F. W. Dunmore
Melville Eastham
Lloyd Espenschied
H. M. Freeman
A. N. Goldsmith
W. A. Graham
L. A. Hazeltine
R. A. Heising
J. V. L. Hogan
C. A. Hoxie
C. B. Jolliffe
F. A. Kolster
F. H. Kroger
R. H. Langley
C. W. Latimer
George Lewis
R. T. S. Lowell
Donald McNicol
R. H. Marriott
J. H. Morecroft
H. W. Nichols
A. A. Oswald
G. W. Pickard
A. E. Reoch
C. E. Speaker
C. H. Taylor
H. M. Turner
Bowden Washington
W. C. White
L. E. Whittemore
C. A. Wright

During 1924 and 1925, the Committee organized several sub-committees each of which prepared drafts of definitions for terms employed in a certain specialized part of the radio field. The names of these sub-committees and their chairmen are as follows:

A. E. Reoch, *Chairman Sub-committee on Radio Telegraph Transmitter Terminology.*
R. H. Langley, *Chairman Sub-committee on Radio Telegraph Receiver Terminology.*
H. W. Nichols } *Joint Chairmen Sub-committee on Radio Telephone Transmitter and*
Lloyd Espenschied } *Receiver Terminology.*
L. A. Hazeltine, *Chairman Sub-committee on Vacuum Tube Terminology.*
C. H. Taylor, *Chairman Sub-committee on Antenna Terminology.*
L. E. Whittemore, *Chairman Sub-committee on Direction Finding Terminology.*

In preparing this report the Committee has recognized the growth in the use of radio by including many terms which were not included in previous reports, but which have either come recently into general use or have become a recognized part of the nomenclature in specialized parts of the radio field. It is hoped, therefore, that this report will be helpful to radio engineers and others by giving such terms and definitions as have gained recognized standing in special branches of radio engineering as well as by indicating what is considered to be good usage of terms in radio literature generally. Trade names have not been included.

The list of terms and definitions has been divided into seven groups in order to facilitate reference to terms which are related to one another in meaning or in use. An alphabetical index is appended.

It was found unnecessary to make any extensive revision of the section giving standard graphical symbols, though a few modifications which were felt to be desirable have been incorporated.

It has been the aim of the Committee to make the report descriptive and explanatory rather than to make the definitions rigorously exact in their phraseology.

The Institute will welcome comments and criticisms which will be helpful in the preparation of revised report in the course of the next two years.

Communications dealing with this work as well as with other Institute matters should be addressed to the Secretary of the Institute of Radio Engineers, 37 West 39th Street, New York City.

DEFINITION OF TERMS USED IN RADIO ENGINEERING

SECTION 1—WAVES AND WAVE PROPAGATION

1001. **Wave**—(a) A propagated disturbance, usually periodic; as, an electric wave or a sound wave.
(b) A single cycle of such a disturbance.
(c) A periodic variation as represented by a graph.

1002. **Wavelength**—The distance traveled in one period or cycle by a periodic disturbance. The distance between corresponding phases of two consecutive waves of a wave train. The quotient of velocity by frequency.

1003. **Continuous Waves**—Alternating electric waves in space, of constant amplitude and frequency. (Abbreviation—cw.)

1004. **Modulated Continuous Waves**—Continuous waves of which the amplitude or frequency is repeatedly varied in accordance with a signal wave.

1005. **Key-Modulated Continuous Waves**—Continuous waves of which the amplitude or frequency is varied by the operation of a transmitting key in accordance with the characters of a communicating code.

1006. **Interrupted Continuous Waves**—Waves obtained by the interruption at audio frequency in a periodic manner of an otherwise continuous wave. (Abbreviation—icw.)

1007. **Damped Waves**—Electromagnetic waves proceeding in wave trains in each of which the amplitude progressively diminishes in successive cycles.

1008. **Signal**—The intelligence, message, or effect conveyed in communication.

1009. **Signal Wave**—A wave, the form of which conveys a signal.

1010. **Carrier Wave**—The component of a modulated wave which has the same frequency as the original unmodulated wave. (See 2005, Carrier Current.)

1011. **Radio Field Intensity**—The root-mean-square value of the electric or magnetic field intensity at a point due to the passage of radio waves. It is often expressed in microvolts per meter.

1012. **Radio Noise Field Intensity**—A measure of the field intensity, at a point (as a radio receiving station), of electromagnetic waves of an interfering character. In practice the quantity measured is not the field intensity of the interfering waves, but some quantity which is proportional to or bears a known relation to the field intensity.

1013. **Signal-Noise Ratio**—The ratio at a point of the field intensity of the radio wave to the radio noise field intensity.

1014. **Strays**—Electromagnetic disturbances in radio reception other than those produced by radio transmitting systems.

1015. **Static**—Conduction or charging current in an antenna resulting from physical contact between the antenna and charged bodies or masses of gas.

In the United States this term has come to be used quite generally as a synonym for atmospherics.

1016. **Atmospherics**—Strays produced by atmospheric conditions.

1017. **Atmospheric Absorption**—A loss of power in transmission of radio waves due to a dissipation in the atmosphere.

1018. **Transmission Loss**—The loss of power suffered by a transmitted wave in passing along a transmission path or through a circuit device. (See 5076, Transmission—Frequency Characteristic.)

1019. **Attenuation**—The reduction in power of a wave or a current with increasing distance from the source of transmission.

1020. **Fading**—The variation of the signal intensity received at a given location from a radio transmitting station as a result of changes in the transmission path. (See 5077, Distortion.)

1021. **Swinging**—The variation in intensity of a received radio signal resulting from changes in the frequency of the transmitted waves.

SECTION 2—TRANSMITTING

2001. **Radio Communication**—The transmission of signals by means of radiated electromagnetic waves originating in a constructed circuit.

2002. **Broadcasting**—The transmission of music, news, entertainment or other intelligence intended for general reception.

2003. **Radiate**—To emit electromagnetic waves into space.

2004. **Radiation**—The process of emitting electromagnetic waves into space.

2005. **Carrier Current**—An alternating current which is modulated by a signal. Ordinarily refers to wire transmission of high-frequency currents. (See 1010, Carrier Wave.)

2006. **Carrier Frequency**—Frequency of a carrier wave or a carrier current.

2007. **Carrier Suppression**—The method of operation in which the carrier wave or carrier current is not transmitted.

2008. **Band of Frequencies**—A continuous range of frequencies extending between two definite frequencies. (See 2012, Radio Channel and 5002, Frequency.)

2009. **Side Bands**—The bands of frequencies, one on either side of the carrier frequency, produced by the process of modulation.

2010. **Side Frequencies**—The frequency on either side of the carrier frequency produced by the process of single frequency modulation.

2011. **Single-Side-Band Transmission**—That method of operation in which one side band is transmitted, and the other side band is suppressed. The carrier wave may be either transmitted or suppressed.

2012. **Radio Channel**—A band of frequencies or wave lengths of a width sufficient to permit of its use for radio communication. The width of a channel depends upon the type of transmission. (See 2008, Band of Frequencies.)

2013. **Radio Transmitting Set (Transmitter)**—A device for producing radio-frequency power and modifying it in accordance with a signal.

2014. **Vacuum Tube Transmitter**—A radio transmitter in which vacuum tubes are utilized to convert the applied electric power into radio-frequency power.

2015. **Oscillator**—A non-rotating device for producing alternating current, the output frequency of which is determined by the characteristics of the device. (See 2018, Radio-Frequency Alternator.)

2016. **Master Oscillator**—An oscillator of comparatively low power so arranged as to control the frequency of the output of an amplifier.

2017. **Tank Circuit**—An intermediate oscillatory circuit associated with the output circuit of a vacuum tube transmitter which absorbs the output of the vacuum tube transmitter in the form of energy impulses of high value and short duration and delivers the power to the load in substantially sinusoidal form.

2018. **Alternator Transmitter**—A radio transmitter which utilizes radio-frequency currents generated by a radio-frequency alternator.

2019. **Radio-Frequency Alternator**—A rotating-type alternating-current generator which generates radio-frequency currents. (See 2015, Oscillator.)

2020. **Load Compensator**—Part of a radio-frequency alternator speed regulator consisting of a device to vary the torque of the motor driving a radio-frequency alternator approximately in accordance with variations of the load on the motor.

2021. **Arc Converter**—A form of oscillator comprising an electric arc used for the conversion of direct to alternating or pulsating current.

2022. **Spark Transmitter**—A radio transmitter which utilizes the oscillatory discharge of a condenser through an inductance and a spark gap as the source of its radio-frequency power.

2023. **Plain Antenna Transmitter**—A spark transmitter in which the spark gap is connected directly in the antenna circuit.

2024. **Spark Gap**—An arrangement of electrodes, used for closing a circuit (usually oscillatory) at a predetermined voltage. The several types of spark gaps are:

(a) **Plain Gap**—A spark gap between two fixed metal electrodes.

(b) **Rotary Gap**—Spark gap in which one of the electrodes is a rotating element which causes a regular change in gap length thereby timing the beginning of the discharge and modifying its duration.

(c) **Synchronous Rotary Gap**—A rotary gap in which the speed of rotation is such that the discharge is synchronous with the alternating voltage applied.

(d) **Quenched Gap**—A spark gap in which the strongly damped discharge current is quickly stopped by the quenching or extinction of the spark.

2025. **Impulse Excitation**—A method of producing damped oscillatory current in a circuit in which the duration of the impressed voltage is short compared with the duration of the current produced.

2026. **Frequency Changer**—A device delivering alternating current at a frequency which differs from the frequency of the supply current.

2027. **Frequency Multiplier**—A frequency changer used to multiply by an integer the frequency of an alternating current.

2028. **Telephone Transmitter**—A sound operated device designed to produce an alternating current the form of which corresponds to that of the sound wave actuating it.

2029. **Microphone**—A telephone transmitter comprising a contact device designed to have its electrical resistance directly and materially altered by slight differences in mechanical pressure.

2030. **Condenser Transmitter**—A telephone transmitter, the operation of which involves a variation in electrostatic capacity produced by a sound wave.

2031. **Modulation**—The process whereby the frequency or amplitude of a wave is varied in accordance with a signal wave.

2032. **Double Modulation**—The process of modulation in which a carrier wave of one frequency is first modulated by the signal wave and is then made to modulate a second carrier wave of another frequency.

2033. **Percentage Modulation**—The variation in amplitude of a modulated wave from its mean value expressed in per cent of the mean value.

2034. **Modulator**—A device to effect the process of modulation. It may be operated by virtue of some non-linear characteristic or by a controlled variation of some circuit quantity.

2035. **Magnetic Modulator** (**Ferromagnetic Modulator**)—A magnetic device employed as a modulator and functioning by virtue of its non-linear magnetization characteristic.

2036. **Vacuum Tube Modulator**—A modulator employing a vacuum tube as a modulating element.

2037. **Duplex Operation**—The operation of associated radio transmitting and radio receiving channels in which transmission and reception are simultaneous.

SECTION 3—RECEIVING

3001. **Receiving Set** (**Receiver**)—A device for converting radio waves into perceptible signals.

3002. **Monitoring Receiver**—A receiver arranged to enable an operator to check the operation of a transmitting set.

3003. **Heterodyne Reception**—The process of receiving radio waves by combining the received current with locally generated alternating current. The locally generated frequency is commonly different from the frequency of the received current, thus producing beats. This is called beat reception.

3004. **Self-Heterodyne Reception** (**Autodyne Reception**)—A system of heterodyne reception through the use of a device which is both an oscillator and a detector.

3005. **Homodyne Reception**—The process of detecting a wave by the aid of a locally generated wave of carrier frequency. (Sometimes called zero-beat reception.)

3006. **Super-Heterodyne Reception**—A method of reception in which the received current is combined with the current from a local oscillator and converted into current of an intermediate frequency which is then amplified and detected to reproduce the original signal wave.

3007. **Intermediate Frequency**—A frequency of a magnitude between that of the carrier employed in radio transmission and the frequency of modulation, and to which the carrier is converted in the super-heterodyne process of reception.

3008. **Reflex Circuit**—An arrangement in which one or more amplifiers are used, each to amplify the signal both before and after detection.

3009. **Tuning**—Primarily, the adjustment of a circuit or circuits to resonance. Use also to mean the adjustment of a circuit or system to secure maximum transmission of a desired signal.

3010. **Sensitivity**—The degree to which a radio receiving set responds to signals of the frequency to which it is tuned.

3011. **Selectivity**—The degree to which a radio receiving set is capable of differentiating between signals of different frequencies.

3012. **Detector**—That portion of the receiving apparatus which, connected to a circuit carrying currents of radio frequency, and in conjunction with a self-contained or separate indicator, translates the radio-frequency power into a form suitable for operation of the indicator. This translation may be effected either by the conversion of the radio-frequency power, or by means of the control of local power. The indicator may be a telephone receiver, relaying device, tape recorder, and so on.

The most common type of detector is a vacuum tube operated on a non-linear portion of its characteristic curve, thereby converting a modulated radio-frequency current into a modulated direct current.

A tube which operates similarly to a detector tube, but the output of which does not operate an indicator, may properly be called a frequency converting tube. (See 5062, Rectifier.)

3013. **Detection Coefficient**—The quotient of the direct current in a radio detector with no external resistance, due to an impressed alternating voltage, divided by the square of the r.m.s. alternating voltage. As most precisely used, the term refers to a voltage so small that its value is independent of the magnitude of the voltage, in which case it is expressed by the equation

$$\text{Detection Coefficient} = \frac{1}{2}\,\frac{d^2i}{de^2}$$

where e and i are respectively the voltage and current as taken from the characteristic curve of the detector with no external resistance. (See 4015, Grid Detection Coefficient and 4039, Mutual Detection Coefficient.)

3014. **Telephone Receiver**—An electrically operated device designed to produce sound waves which correspond to the signal current actuating it.

3015. **Loud Speaker**—A telephone receiver designed to produce sound of sufficiently large volume to be heard at a substantial distance.

3016. **Interference**—Confusion of reception due to strays, undesired signals or other causes; also that which produces the confusion.

SECTION 4—VACUUM TUBES

4001. **Vacuum Tube**—A device consisting of a number of electrodes contained within an enclosure evacuated to a low pressure. This term is also commonly used less broadly in referring to the type of vacuum tube having grid, plate and filament (triode).

4002. **Diode**—A type of vacuum tube containing two electrodes which passes current wholly or predominantly in one direction.

Note—A vacuum tube having a single cathode and two anodes which operate alternately may properly be called a **double diode.**

4003. **Triode**—A type of vacuum tube containing an anode, a cathode and a third electrode, in which the current flowing between the anode and the cathode is controlled by the relative potential of the third or control electrode.

4004. **Cathode**—The electrode to which the current flows through the vacuous space. The cathode is usually the source of the electron emission which constitutes this current. (See 4005, Filament.)

4005. **Filament**—The cathode in the common type of vacuum tube (triode).

4006. **Filament Voltage**—The voltage between the terminals of the filament.

4007. **Filament Current**—The current supplied to the filament to heat it.

Note—When the filament is heated by direct current which is not large in comparison with the plate current, the filament current is ordinarily measured at that filament terminal where it is the larger.

4008. **Control Electrode**—The electrode, the relative potential of which controls the current flowing between the anode and the cathode. (See 4009, Grid.)

4009. **Grid**—The common name for the control electrode in a vacuum tube.

4010. **Grid Potential**—The electric potential of the grid relative to the cathode. (See note under 4020, Plate Potential.)

4011. **Grid Current**—The conduction current passing from the grid through the vacuous space.

4012. **Reversed Grid Current**—The conduction current passing to the grid through the vacuous space.

4013. **Grid Conductance**—The quotient of the change in grid current divided by the change in grid potential producing it, under the condition of constant plate potential. As most precisely used, the term refers to infinitesimal changes, as indicated in the defining equation

$$\text{Grid conductance, } g_g = \frac{di_g}{de_g}, \; e_p = \text{const.}$$

Note—The grid conductance is the resistive component of the input admittance of the vacuum tube. (See 4024, Plate Conductance.)

4014. **Grid Characteristic Curve**—The curve plotted between grid potential as abscissa and grid current as ordinate. (See 4026, Plate Characteristic Curve; 4040, Mutual Characteristic Curve and 4043, Emission Characteristic Curve.)

4015. **Grid Detection Coefficient**—The quotient of the change in the direct grid current produced in a vacuum tube with no external grid or plate resistance, due to an impressed alternating grid voltage, divided by the square of the r.m.s. alternating voltage. As most precisely used, the term refers to a grid voltage so small that its value is independent of the magnitude of the voltage, in which case it is expressed by the equation

$$\text{Grid detection coefficient} = \frac{1}{2}\,\frac{d^2 i_g}{de_g^2}, \; e_p = \text{const.}$$

where e_g and i_g are respectively the grid potential and the grid current. (See 3013, Detection Coefficient and 4039, Mutual Detection Coefficient.)

4016. **Grid Condenser**—A condenser connected in series in the grid or control circuit of a vacuum tube.

4017. **Grid Leak**—A resistor usually of very high resistance, used in association with a condenser and connected directly or indirectly between the cathode and the grid of a vacuum tube.

4018. **Anode**—The electrode from which the current flows through the vacuous space. (See 4019, Plate.)

4019. **Plate**—The common name for the anode in a vacuum tube.

4020. **Plate Potential**—The electric potential of the plate relative to the cathode.

Note—If the cathode is a filament heated by direct current, its negative terminal is ordinarily taken as the datum of potential; if heated by alternating current, its mid-point is taken as the datum.

4021. **Plate Current**—The conduction current passing from the plate through the vacuous space.

4022. **Amplification Factor**—A measure of the effectiveness of the grid potential relative to that of the plate potential in affecting the plate current; it is the quotient of the change in plate potential divided by the negative change in grid potential, under the condition that the plate current remains unchanged. As most precisely used, the term refers to infinitesimal changes in the potentials as indicated in the defining equation

$$\text{Amplification factor } \mu = -\frac{de_p}{de_g}, \ i_p = \text{const.}$$

(See 5044, Voltage Amplification.)

4023. **Mutual Conductance**—The quotient of the change in plate current divided by the change in grid potential producing it, under the condition of constant plate potential. As most precisely used, the term refers to infinitesimal changes, as indicated in the defining equation

$$\text{Mutual conductance, } g_m = \frac{di_p}{de_g}, \ e_p = \text{const.}$$

The unit ordinarily used is the microohm.

Note—In rare cases, when the dependence of the grid current on the plate potential is to be considered, the following terms and symbols may be employed:

Inverse amplification factor

$$\mu_n = -\frac{de_g}{de_p}, \ i_g = \text{const.}$$

Inverse mutual conductance,

$$g_n = \frac{di_g}{de_p}, \ e_g = \text{const.}$$

(See 4040, Mutual Characteristic Curve.)

4024. **Plate Conductance**—The quotient of the change in plate current divided by the change in plate potential producing it, under the condition of constant grid potential. As most precisely used, the term refers to infinitesimal changes, as indicated in the defining equation

$$\text{Plate conductance, } g_p = \frac{di_p}{de_p}, \ e_g = \text{const.}$$

Note—The plate conductance is the resistive component of the internal output admittance of a vacuum tube. (See 4013, Grid Conductance.)

4025. **Plate Resistance**—The reciprocal of the plate conductance.

$$r_p = \frac{1}{g_p} = \frac{de_p}{di_p}, \ e_g = \text{const.}$$

Note—The following relations exist between the terms numbered 4022, 4023, 4024 and 4025.

$$g_m = \mu g_p = \frac{\mu}{r_p}$$

4026. **Plate Characteristic Curve**—The curve plotted between plate potential as abscissa and plate current as ordinate. (See 4014, Grid Characteristic Curve; 4040, Mutual Characteristic Curve and 4043, Emission Characteristic Curve.)

4027. **Plate Choke Coil**—A coil of relatively high inductance inserted in the anode supply circuit of a vacuum tube amplifier, modulator, or oscillator to maintain substantially constant current in this circuit throughout a cycle of the amplified or generated current.

4028. **Filament Capacity** (C_f)—The sum of the direct capacities between the filament and all other conductors of a vacuum tube.

4029. **Grid Capacity** (C_g)—The sum of the direct capacities between the grid and all other conductors of a vacuum tube.

4030. **Plate Capacity** (C_p)—The sum of the direct capacities between the plate and all other conductors of a vacuum tube.

4031. **Direct Capacity** (C)—between two conductors—The quotient of the charge produced on one conductor by the voltage between it and the other conductor divided by this voltage, all other conductors in the neighborhood being at the potential of the first conductor.

4032. **Grid-Plate Capacity** (C_{gp})—The direct capacity between the grid and the plate.

4033. **Grid-Filament Capacity** (C_{gf})—The direct capacity between the grid and the filament. (See 4032, Grid-Plate Capacity.)

4034. **Plate-Filament Capacity** (C_{pf})—The direct capacity between the plate and the filament. (See 4032, Grid-Plate Capacity.)

Note—All capacities are ordinarily understood to be taken with the vacuum tube in its completed form but not in its socket or other holder.

Note—The capacities C_{pf}, C_{gf} and C_{gp} are not those ordinarily directly measured, but are computed from the direct capacities which can be directly measured, in accordance with the following equations:

$$C_f = C_{gf} + C_{pf}; \qquad C_p = C_{pf} + C_{gp}; \qquad C_g = C_{gf} + C_{gp};$$

$$C_{pf} = \frac{C_p + C_f - C_g}{2}; \qquad C_{gf} = \frac{C_g + C_f - C_p}{2}; \qquad C_{gp} = \frac{C_g + C_p - C_f}{2}$$

4035. **Internal Output Impedance** (of any electrical device having output terminals)—The quotient of the alternating voltage impressed on the output terminals divided by the alternating current thereby produced at these terminals, in the absence of impressed alternating voltages at other points.

Note—This is sometimes called simply "output impedance," but the prefix "internal" is preferred in order more surely to distinguish it from the impedance of the external output circuit.

4036. **Internal Output Admittance**—The reciprocal of internal output impedance.

4037. **Input Impedance** (of any electrical device)—The quotient of the alternating voltage impressed on the input terminals of the device divided by the alternating current thereby produced at these terminals, in the absence of impressed alternating voltages at other points.

4038. **Input Admittance**—The reciprocal of input impedance.

4039. **Mutual Detection Coefficient** of a vacuum tube—The quotient of the change in the direct space current produced in a triode with no external grid or plate resistance, due to an impressed alternating grid voltage, divided by the square of the r.m.s. alternating voltage. As most precisely used, the term refers to a grid voltage so small that its value is independent of the magnitude of the voltage, in which case it is expressed by the equation

$$\text{Mutual detection coefficient} = \frac{1}{2}\,\frac{d^2 i_p}{de_g{}^2}, \quad e_p = \text{const.}$$

(See 3013, Detection Coefficient and 4015, Grid Detection Coefficient.)

4040. **Mutual Characteristic Curve (Grid-Plate Characteristic Curve)**—The curve plotted between the grid voltage as abscissa and the plate current as ordinate. (See 4014, Grid Characteristic Curve; 4023, Mutual Conductance; 4026, Plate Characteristic Curve and 4043, Emission Characteristic Curve.)

4041. **Electron Emission**—The phenomenon of the liberation of electrons from the surface of a body into the surrounding space, usually under the influence of heat, ultra-violet rays, x-rays, impact excitation, or chemical disintegration.

4042. **Emission Current**—The value of the current carried by electrons emitted from a cathode under the influence of a voltage such as will draw away all the electrons emitted.

4043. **Emission Characteristic Curve**—The curve plotted between a factor controlling electron emission (such as the temperature, voltage or current of the cathode or filament) as abscissa and the emission current from the cathode or filament as ordinate. (See 4014, Grid Characteristic Curve; 4026, Plate Characteristic Curve and 4040, Mutual Characteristic Curve.)

4044. **Thermionic**—Relating to electron emission under the influence of heat.

SECTION 5—CIRCUIT ELEMENTS AND PROPERTIES

5001. **Cycle**—One complete set of positive and negative values of an alternating current.

5002. **Frequency**—The number of cycles per second. (See 2008, Band of Frequencies.)

5003. **Kilocycle** (strictly kilocycle per second or cycle per millisecond)—A thousand cycles per second.

5004. **Megacycle** (strictly megacycle per second or cycle per microsecond)—A million cycles per second.

5005. **Audio Frequencies**—The frequencies corresponding to normally audible sound waves. The upper limit ordinarily lies between 10,000 and 20,000 cycles.

5006. **Radio Frequencies**—The frequencies higher than those corresponding to normally audible sound waves. (See 5005, Audio Frequencies.)

Note—It is not implied that radiation cannot be secured at lower frequencies, nor that radio frequencies are necessarily above the limit of audibility.

5007. **Group Frequency**—The number of trains of damped waves or current per second.

Note—The term "group frequency" has replaced the term "spark frequency."

5008. **Resonance Frequency** (of a circuit)—The frequency at which the supply current and supply voltage of the circuit are in phase.

5009. **Frequency Meter**—An instrument for measuring frequency. (Frequency meters used in radio work are sometimes called wavemeters.)

5010. **Fundamental Frequency**—That frequency of which all component frequencies are integral multiples.

5011. **Fundamental Wavelength**—The wavelength corresponding to fundamental frequency.

5012. **Harmonic**—A component of a periodic quantity having a frequency which is an integral multiple of the fundamental wave frequency. For example, a component, the frequency of which is twice the fundamental frequency, is called the second harmonic.

5013. **Periodic Current**—Periodically reversing current the frequency of which is determined by the electrical constants of the circuits in which it flows. It may be either damped or continuous.

5014. **Oscillatory Circuit**—A relatively low resistance circuit containing both inductance and capacity, such that a voltage impulse will produce a current which periodically reverses.

5015. **Beating**—A phenomenon in which two or more periodic quantities of not greatly different frequencies react with each other to produce a resultant having pulsations of amplitude.

5016. **Beat**—A complete cycle of such pulsations.

5017. **Beat Frequency**—The number of beats per unit of time. This frequency is equal to the difference between the frequencies of the combining waves.

5018. **Series Resonance**—A condition which exists in a circuit having inductance and capacity connected in series, when the supply current and supply voltage are in phase.

5019. **Parallel Resonance**—A condition which exists in a circuit having inductance and capacity connected in parallel, when the supply current and supply voltage are in phase.

5020. **Acceptor**—A circuit having inductance and capacity so arranged and tuned as to offer low impedance to currents of a given frequency, and high impedance to currents of any other frequency. (See 5021, Rejector.)

5021. **Rejector**—A circuit having inductance and capacity so arranged and tuned as to offer high impedance to the flow of currents of a given frequency and low impedance to currents of all other frequencies. (See 5020, Acceptor.)

5022. **Coupling**—The association of two circuits in such a way that energy may be transferred from one to the other.

5023. **Coupling Coefficient**—The ratio of the mutual or common impedance component of two circuits to the square root of the product of the total impedance components of the same kind in the two circuits. (Impedance components may consist of inductance, capacity or resistance.)

5024. **Direct Coupling**—Association of two radio circuits by having an inductor, a condenser, or a resistor, common to both circuits.

5025. **Inductive Coupling**—The association of one circuit with another by means of inductance common or mutual to both. (This term when used without modifying words is commonly used for coupling by means of mutual inductance, whereas coupling by means of self-inductance common to both circuits is called "direct inductive coupling.")

5026. **Capacity Coupling**—The association of one circuit with another by means of capacity common or mutual to both.

5027. **Resistance Coupling**—The association of one circuit with another by means of resistance common to both.

5028. **Coupler**—An apparatus which is used to transfer radio-frequency power from one circuit to another by associating together portions of these circuits. Couplers are of the same types as the types of coupling—inductive, capacity, and resistance.

5029. **Coupling Coil**—An inductance coil used as a coupler.

5030. **Coupling Condenser**—A condenser used to produce coupling between two circuits.

5031. **Decremeter**—An instrument for measuring the logarithmic decrement of a train of waves.

5032. **Logarithmic Decrement**—The Napierian logarithm of the ratio of the first to the second of two successive amplitudes in the same direction, for an exponentially damped alternating current. The logarithmic decrement can also be considered as a constant of a simple radio circuit, being π times the product of the resistance by the square root of the ratio of the capacity to the inductance of the circuit.

5033. **Damping Constant**—The Napierian logarithm of the ratio of two values of an exponentially decreasing quantity separated by unit time. (This is preferred to the term "damping factor.")

The coefficient "a" appearing in the exponent of the damping factor, ϵ^{-at}, which occurs in expressions of the following forms for damped currents.

$$i = I_0 \epsilon^{-at}$$

$$i = I_0 \epsilon^{-at} \cos 2\pi f_n t$$

In an oscillatory circuit containing resistance, inductance, and capacity in series, $a = R/2L$.

5034. **Alternating Current**—A current, the direction of which reverses at regularly recurring intervals, the algebraic average value being zero.

5035. **Damped Alternating Current**—A current passing through successive cycles with progressively diminishing amplitude.

5036. **Free Alternating Current**—The damped alternating current which flows in a circuit following the cessation of an impressed voltage.

5037. **Forced Alternating Current**—The alternating current which flows in a circuit as the result of an impressed alternating voltage and which has the same frequency.

5038. **Pulsating Current**—A periodic current (that is, current passing through successive cycles), the algebraic average value of which is not zero. A pulsating current is equivalent to the sum of an alternating and a constant amplitude direct current.

5039. **Direct Current**—A unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

5040. **Hot-Wire Ammeter**—(Extension type)—An ammeter dependent for its indications on a change in dimensions of an element which is heated by a current through it.

5041. **Thermocouple Ammeter**—An ammeter dependent for its indications on the change in thermo electromotive force set up in a thermo electric couple which is heated by the current to be measured.

5042. **Vacuum Tube Voltmeter**—A device for measuring small voltages consisting of a vacuum tube having an ammeter in its output circuit. The scale deflections are calibrated in terms of the voltage applied to the grid circuit.

5043. **Amplifier**—A device for increasing the amplitude of electric current or voltage, through the control by the input power of a larger amount of power supplied by a local source to the output circuit.

5044. **Voltage Amplification**—The ratio of the alternating voltage produced at the output terminals of an amplifier to the alternating voltage impressed at the input terminals. (This term should not be used to describe a process.) (See 4022, Amplification Factor.)

5045. **Current Amplification** (of an amplifier)—The ratio of the alternating current produced in the output circuit to the alternating current supplied to the input circuit.

5046. **Power Amplification** (of an amplifier)—The ratio of the alternating-current power produced in the output circuit to the alternating-current power supplied to the input circuit.

5047. **Power Amplifier**—An amplifier which is capable of producing relatively large power in an output circuit.

5048. **Relay**—A device in which the input power is used to control a local source of power in the output circuit.

5049. **Regeneration**—The process by which a part of the output power of an amplifying device reacts upon the input circuit in such a manner as to reinforce the initial power, thereby increasing the amplification. (Sometimes called "feed back.")

5050. **Attenuation Equalizer**—A device for altering the attenuation of a circuit for various frequencies in order to make substantially equal the total attenuation for all frequencies within a certain range.

5051. **Transmission Level**—The radio field intensity or the signaling power amplitude at any point in a communication system, expressed either in some absolute unit or with reference to an arbitrary base value.

5052. **Transmission Unit** (Abbreviation TU)—A unit of power ratio used for expressing transmission loss or transmission gain (amplification). Two amounts of power differ by one transmission unit when they are in the ratio of $10^{0.1}$. Two amounts of power differ by N transmission units when they are in the ratio of $10^{(0.1)N}$. The number of transmission units is ten times the common logarithm of the power ratio to be expressed; i.e., $10 \log_{10}\frac{P_1}{P_2}$.

Power Ratio		TU	
1	$(=10^0)$	0	$(=10 \log_{10} 1)$
1.259	$(=10^{0.1})$	1	$(=10 \log_{10} 1.259)$
10	$(=10^1)$	10	$(=10 \log_{10} 10)$
100	$(=10^2)$	20	$(=10 \log_{10} 100)$
1000	$(=10^3)$	30	$(=10 \log_{10} 1000)$

For current ratios, the number of transmission units is equal to 20 times the common logarithm of the current ratio (with constant impedance) to be expressed; i.e., $20 \log_{10}\frac{I_1}{I_2}$.

Current Ratio	TU
0.001	−60.00
0.005	−46.02
0.01	−40.00
0.05	−26.02
0.1	−20.00
0.2	−13.98
0.5	− 6.02
1.0	0.00
1.5	3.52

Current Ratio	TU
2	6.02
5	13.98
10	20.00
20	26.02
50	33.98
100	40.00
500	53.98
1000	60.00

5053. **Loading Coil**—An inductance coil, usually not inductively coupled to any other circuit, for connection in a tuned circuit to decrease its resonant frequency.

5054. **Choke Coil**—An inductance coil inserted in a circuit to offer reactance to the flow of alternating current components while allowing direct current to pass.

5055. **Banked Winding**—A form of coil winding in which single turns are wound successively in each of two or more layers, the winding proceeding from one end of the coil to the other, without return.

5056. **By-Pass Condenser**—A condenser used to provide a path of comparatively low impedance around some circuit element.

5057. **Stopping Condenser**—A condenser used to insert a comparatively high impedance in some branch of a circuit for the purpose of limiting the flow of low frequency alternating current or direct current without materially affecting the flow of high frequency alternating current.

5058. **Filter**—A selective circuit network designed to transmit alternating-currents within a continuous band or bands of frequencies and attenuate currents of all frequencies outside the transmission band or bands.

5059. **Low-Pass Filter**—A filter designed to transmit currents of all frequencies below a critical or cut-off frequency and attenuate currents of all frequencies above this critical frequency.

5060. **High-Pass Filter**—A filter designed to transmit currents of all frequencies above a critical or cut-off frequency and attenuate currents of all frequencies below this critical frequency.

5061. **Band-Pass Filter**—A filter designed to transmit currents of frequencies within a continuous band limited by an upper and a lower critical or cut-off frequency and attenuate currents of all frequencies outside of that band.

5062. **Rectifier**—A device whose resistance for currents in one direction differs from its resistance for currents in the other direction and which is used to convert an alternating-current wave into a unidirectional wave.

Note—In dealing with rectification in the reception of radio signals the term "detector" or "converter" is preferred to "rectifier." (See 3012, Detector.)

5063. **Half-Wave Rectifier**—A rectifier which changes alternating current into pulsating, unidirectional current, utilizing only one-half of each cycle.

5064. **Full-Wave Rectifier**—A double rectifier arranged so that current is allowed to pass in the same direction to the load circuit during each half cycles of the alternating-current supply, one element functioning during one-half cycle and the other during the next half cycle, and so on.

5065. **Vacuum Tube Rectifier**—A device for rectifying an alternating current by utilizing the electron flow between two electrodes in a vacuum or in a gas.

5066. **Resonance Transformer**—A transformer with condenser load, whose circuits are adjusted as a whole to have the same frequency as that of the alternating current supplied to the primary, thereby causing the secondary voltage to build up to higher values than would otherwise be attained.

5067. **Radio-Frequency Transformer**—A transformer for use with radio-frequency currents.

5068. **Audio-Frequency Transformer**—A transformer for use with audio-frequency currents.

5069. **Rheostat**—A resistor which is provided with means for readily varying its resistance.

5070. **Potentiometer**—A device consisting of a resistor provided with a movable or sliding contact in addition to its terminal contacts. It is used as a voltage divider. The current is passed between the terminal contacts and the desired difference of potential is obtained between one terminal contact and the movable contact. ("Voltage divider" is a preferred term.)

5071. **"A" Battery**—A battery which provides heating current for the filament of a vacuum tube.

5072. **"B" Battery**—A battery connected in the plate circuit of a vacuum tube, for the purpose of supplying power to the plate circuit.

5073. **"C" Battery**—A battery connected in the circuit between the filament and grid of a vacuum tube so as to apply a potential to the grid.

5074. **Protective Device**—A device for keeping currents or voltages of undesirably large magnitude out of a given part of an electrical circuit. For example, fuse, lightning arrestor.

5075. **Quality**—(In broadcasting)—The degree to which sound is faithfully reproduced.

5076. **Transmission-Frequency Characteristic**—The variation with frequency of the transmission efficiency of a circuit or transmission path. (See 1018, Transmission Loss.)

5077. **Distortion**—A change in wave form as in passing through a circuit or transmission medium. A wave form may be distorted by:

(a) The presence in the output of components having frequencies not present in the original wave due to circuit elements having non-linear characteristics.

(b) A change in the relative amplitude of the component frequencies due to variation in the transmission efficiency over the frequency range involved.

(c) A change in the relative phase of the component frequencies. (Not a cause of distortion when present in audio-frequency waves.)

Two or more of these forms of distortion may exist simultaneously. (See 1020, Fading.)

SECTION 6—ANTENNAS

6001. **Antenna**—A device for radiating or absorbing radio waves.

6002. **Aerial**—The elevated conductor portion of a condenser antenna.

6003. **Beam Antenna**—A unilateral directive antenna such that its radiation is substantially confined to a narrow beam.

6004. **Unlateral Antenna**—An antenna having the property of radiating or receiving radio waves in larger proportion in some one angular region than in all other directions.

6005. **Bi-Lateral Antenna**—An antenna having the property of radiating or receiving radio waves in larger proportion in angular regions 180 degrees apart than in all other directions.

6006. **Cage Antenna**—An antenna having conductors which consist of groups of parallel wires arairnged as the elements of a cylinder.

6007. **Coil Antenna**—An antenna consisting of one or more complete turns of wire.

6008. **Condenser Antenna**—An antenna consisting of two capacity areas.

6009. **Directive Antenna**—An antenna having the property of radiating radio waves in larger proportion along some directions than others.

6010. **Directional Antenna**—An antenna having the property of radiating or receiving radio waves in larger proportion along some directions than others.

6011. **Flat Top Antenna**—An antenna having approximately horizontal conductors at the top.

6012. **Harp Antenna**—An antenna composed of vertical, or approximately vertical conductors, all in one plane.

6013. **Inverted Antenna**—A flat top antenna in which the lead-in is taken from one end of the horizontal portion.

6014. **Multiple Tuned Antenna**—An antenna with connections to ground through inductances at more than one point, the inductances being so determined that their reactances in parallel present a total reactance equal to that necessary to give the antenna the desired natural frequency.

6015. **Feed Ratio** (of a multiple tuned antenna)—The value obtained by dividing the sum of the currents at all the antinodes by the current in the line feeding the antenna.

6016. **Series or Feed Resistance** (of a multiple tuned antenna)—The quotient of the power delivered to the antenna by the square of the current in the line feeding the antenna.

6017. **T Antenna**—A flat top antenna in which the lead-in is taken from the center of the horizontal portion.

6018. **Umbrella Antenna**—An antenna, the conductors of which form elements of a cone with the apex at the top to which the lead-in is connected.

6019. **Wave Antenna**—A horizontal aerial, the physical length of which is of the same order of magnitude as that of the signaling waves to be received, and which is so used as to be strongly directional.

6020. **Antenna Resistance**—An effective resistance which is numerically equal to the quotient of the average power in the entire antenna circuit by the square of the effective current at the point of maximum current.

Note: Antenna resistance includes: Radiation resistance, ground resistance, radio-frequency resistance of conductors in antenna circuit, equivalent resistance due to corona. eddy currents, insulator leakage, dielectric loss, and so on.

6021. **Effective Height of an Antenna**—The height of an equivalent ideal antenna producing the same radiated field. As ordinarily defined, this ideal antenna is a vertical conductor carrying a uniform current equal to the maximum current existing at any point in the actual antenna.

6022. **Meter Amperes**—The product of the antenna current in amperes at the point of maximum current and the antenna effective height in meters for any radio transmitting station. It constitutes a factor for indicating the radiating strength of radio transmitting stations.

6023. **Antenna Form Factor**—The ratio of the effective height of an antenna to its actual physical height.

6024. **Radiation Resistance**—The quotient of the total power radiated by an antenna by the square of the effective current at the point of maximum current.

6025. **Radiation Efficiency**—The radiation efficiency of an antenna is the ratio of power radiated to the total power delivered to the antenna, at a given frequency.

6026. **Fundamental or Natural Frequency** (of an antenna)—The lowest resonant frequency of an unloaded antenna. (Unloaded, i.e., without added inductance or capacity.)

6027. **Lead-In**—That portion of an antenna system which completes the electrical connection between the elevated outdoor portion and the instruments or disconnecting switches inside the building.

6028. **Antenna Loading Coil**—A coil, inserted to increase the inductance of the antenna circuit.

6029. **Counterpoise**—A system of wires or other conductors, forming the lower capacity area of a condenser antenna elevated above and insulated from the ground and substantially as extensive as the aerial.

6030. **Ground System** (of an antenna)—That portion of the antenna system below the antenna loading devices or generating apparatus most closely associated with the ground and including the ground itself.

6031. **Ground Wire**—A conductive connection to the earth.

6032. **Ground Equalizer Inductors**—Coils of relatively low inductance placed in the circuit connected to one or more of the grounding points of an antenna ground system, to divide the current between the various points in any desired way.

SECTION 7—DIRECTION FINDING

7001. **Direction Finder (Radio Compass or Goniometer)**—A radio receiving device which permits determination of the line of travel of waves as received from transmitting station.

7002. **Direction Finder Calibration**—The determination of the direction and amount of local wave front distortion to the end that the true bearing may be determined from the apparent bearing given by the direction finder.

7003. **Radio Wave Front Distortion**—A change in the direction of advance of radio waves.

7004. **Unidirectional Radio Direction Finder (Sense Radio Direction Finder)**—A radio receiving device which permits determination of the direction (without 180° ambiguity) of waves as received from a transmitting station.

7005. **Radio Beacon**—A radio transmitting station in a fixed geographic location which emits a distinctive or characteristic signal for enabling mobile receiving stations to determine bearings.

7006. **Equisignal Radio Beacon**—A radio beacon which transmits two distinctive signals which may be received with equal intensity only in certain directions.

7007. **Equisignal Zone**—The region in which the two distinctive signals from an equisignal radio beacon are received with equal intensity.

7008. **Observed Radio Bearing**—The angular deviation from an arbitrary fixed line, such as the earth's geographical meridian or the fore and aft line of a ship, of the direction of the incoming wave as determined by a radio direction finder (without calibration correction).

7009. **Corrected Radio Bearing**—An observed radio bearing to which the calibration correction has been applied.

7010. **True Radio Bearing**—The angular deviation from true North, at the point of observation, of the chord of the great circle passing from the observer, to a given transmitting station.

7011. **Fix**—The intersection of the lines of direction of two or more bearings.

7012. **Balancing Condenser**—A condenser used for equalizing the potentials at the terminals of a direction finder coil when set in the position of minimum signal.

STANDARD GRAPHICAL SYMBOLS

Ammeter

Antenna or Aerial

Arc

Battery

Battery (polarity indicated)

Buzzer

Coil Antenna

Condenser, Fixed

Condenser, Shielded

Condenser, Variable

Condenser, Variable
(with moving plate indicated)

Counterpoise

Coupler, Inductive
(Mutual inductor)

Coupler, Inductive
(with variable coupling)

Crystal Detector

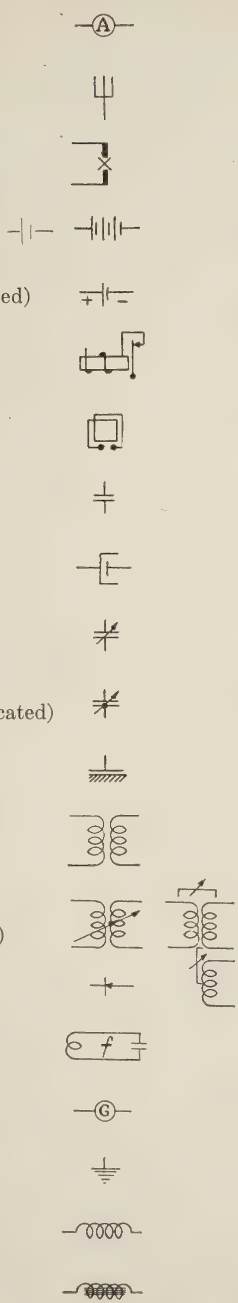
Frequency Meter
(Wavemeter)

Galvanometer

Ground

Inductor

Inductor, Iron Core



Inductor, Variable

Inductor, Adjustable

Jack

Key

Lightning Arrester

Resistor

Resistor, Variable

Spark Gap, Non Synchronous

Piezoelectric Crystal

Spark Gap, Plain

Spark Gap, Quenched

Spark Gap, Synchronous

Telephone Receiver

Loud Speaker

Telephone Transmitter
(Microphone)

Thermoelement

Transformer

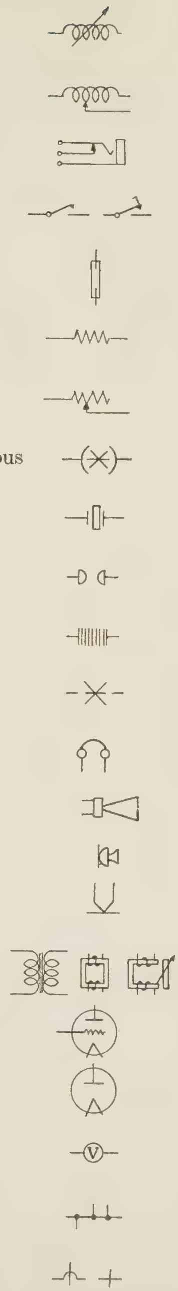
Vacuum Tube, Triode

Vacuum Tube, Diode

Voltmeter

Wires, Joined

Wires, Crossed not joined



INDEX

Errata sheet for Radio Manual

age	Chapt.	Par.	Fig.	Line	
3	I	22		3 4	Insert parenthesis before "which" and after memorized.
6	VI	21		4	Change "had to "has".
8	IX		9		Delete "saturation current".
13	IX	91		9 10	Delete "whereby" Change "produced" to "produce".
19	IX	121		4	After "impedance" insert "(which in actual practice is the grid leak.)
19	IX		20		Make C_2 variable by inserting arrow.
21	IX	128			Write in new paragraph attached.
3	X	15			Equation 1. last term should be I_pR_o. Equation 2. third term should be $I_{gp}X_{cgp}$.
3	X				At top of page change $\frac{gm}{gp}$ to read $\frac{gm}{gp}E_g$
6	X		6c		Change "Grid Power Input = I_xI_g"to read I_xE_g.
7	X		6d		Same.
9	X	46		4	Add "c" to "chara".
	X	77			Write new paragraph attached.
4	XIII		5		Insert a key between b and (-) filament.
10	XIII		11		Make C_4 and C_5 variable.
11	XIII		12		Same.

Errata sheet for Radio Manual

Chapter IX.

128 - A.C. TUBES.

Although A.C. has been used for transmitting tubes for some years, it is only comparatively recently that successful A.C. receiving tubes have been developed. The obvious advantage of such a tube is the complete elimination of filament lighting batteries - the familiar storage batteries with the attendant bother of keeping them charged and watered - and securing filament lighting power from light sockets thru stepdown transformers. The main drawback to the production of an A.C. filament tube has been the A.C. hum caused by grid-plate effect. If the grid return is made to the common -A, -B, as is usual, the alternations of the filament voltage will act on the grid and plate of the tubes exactly as a signal voltage and will produce a loud 120 cycle hum. A tube has recently been developed which uses raw A.C. on the filament. It is in general commercial use in A.C. receivers, being used as a R.F. and A.F. amplifier tube. It is designated UX226. It depends upon the high thermal inertia of its filament for successful operation on A.C. The inertia is sufficient to hold the emission fairly constant even though the voltage supplied is alternating. The grid return is connected to the filament at the electrical center of a resistance which is shunted across the filament. Induced A.C. hum may be balanced out by careful adjustment of the position of this center tap.

This type of tube is not adaptable to the detector with grid leak, grid condenser operation, as it is susceptible to any stray low frequency electric disturbances. In order to eliminate the hum in the detector a heater-cathode method is used. Heating the filament is essential for the production of electronic emission. With the heater-cathode method electrons are emitted by another strip of metal (the cathode) placed close to the filament and heated by it. Such tubes have five prongs, two for the filament, one each for the cathode, grid and plate. The grid return is connected to the cathode thereby eliminating any direct connection between the filament circuit and the other circuits. One example of such a tube is the UY227.

Chapter X.

77. As was pointed out in par. 128, Chap. IX, the development of heater-cathode tubes was slow because of the difficulty of eliminating the hum produced by the A.C. filament voltage. It is not hard to see the difficulties attendant upon the production of a heater-cathode screen grid tube, with its enormously increased amplification. However, this has recently been accomplished by the UY224 tube.